LAND USE, SOIL EROSION, AND FARMERS' ATTITUDES TOWARDS CONSERVATION: BASIS FOR LAND MANAGEMENT POLICIES IN LAS CUEVAS WATERSHED, DOMINICAN REPUBLIC

By

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Multiple analysis is performed on main obstacles to implement soil conservation in the subtropical mountainous watershed of Las Cuevas in the southwestern Dominican Republic. Physical and behavioral components are incorporated in the analyses, combining information from a soil survey and a sample of farms.

Using the concept of erosion potential and making partial application of the Universal Soil Loss Equation (USLE), an erosion risk index was estimated for 423 sampled sites. Interpolation, frequency analysis and computer mapping permitted the differentiation of three spatial units with moderate, high, and very high erosion risk. These units served to design a stratified random sampling of farms from cadastral information. Interviews with the respective farmers provided the basic data for the analyses.

Spatial organization of land use within rainfed farms was found to depend greatly on the variations of the topography and physical attributes of the soil. However, this relationship between land use and erosion potential is not expressed by any soil conservation point of view on the part of farmers. In fact, many farms are organized in such a way that row crops are frequently on steeper slopes and permanent crops on less steep ones. This suggests that farmers seem to reserve permanent crops for those plots with better soil depth and moisture conditions. Farmers with rainfed farms, perhaps, are more worried about the performance of the permanent food crops such as plantains, which have longer productive cycles and are daily foods in the diet of the people of the region, than about row crops.

Discriminant analysis demonstrated that it is possible to predict perceivers and non-perceivers of soil erosion on the basis of some farm characteristics. It is suggested that farmers are inclined to perceive the erosion problem only when it has reached critical stages. Those farmers who operate farms with gullies, shallow soils and steeper slopes are more likely to perceive the problem caused by soil erosion and therefore will be more interested in soil conservation programs.

Analyses through a damage function showed that the profitability of soil conservation adoption in Las Cuevas is very much related to the farmers' planning horizon, technological level, conservation costs and the relationship between soil depth and crop yields.

CHAPTER I
INTRODUCTION

Problem Statement

The need for soil conservation was emphasized by Bennett (1939), Jacks and Whyte (1949) and many others in the mid 1930s to early 1950s, but so little has been achieved that more recent reports (FAO, 1965, Fournier, 1972) are virtually indistinguishable in factual content and sentiment from earlier studies. The need for soil conservation is as great today as it was in past years. Yet, even under the impetus of the U.S. Soil Conservation Service and U.S. Department of Agriculture, conservation measures are not widely adopted in this country. The need for soil conservation is similar in other areas of the developed world.

It is not surprising, then, that soil conservation is not widely practiced in the Third World, where erosion is a great cause of concern. Increasing soil erosion is adversely affecting many farmers in tropical and subtropical steeplands where marginal agriculture is carried out. Protection against soil erosion in these areas is needed to sustain farm yields, to avoid environmental degradation, to prolong the longevity of stream reservoirs, and to prevent deeper inroads of poverty into the rural farming population.

Control of soil erosion, which means reducing the rate of soil erosion to a tolerable level, relies on selecting appropriate conservation policies. Wise strategies, adapted to local and regional conditions, have to be based upon the identification and analytical understanding of the main physical, cultural, institutional, and socioeconomic constraints for farmers' use and adoption of soil conservation practices. Studies that embody this holistic approach are very scarce in the Third World, particularly in Latin America (Rocheleau, 1983). Literature on these topics traditionally has been fragmental or monotopically oriented, and has affected only slightly public agencies' efforts to design and implement soil conservation and agricultural development projects.

Most attempts to promote soil conservation programs have failed, and future efforts will fail unless a comprehensive understanding is developed about the relationship between soil erosion and farmers' behavior with respect to soil conservation. Investigating the nature of this relationship at both regional and farm levels will improve the planning and implementation of soil conservation extension services. Figure 1.1 shows the central components and flows affecting the success or failure of a soil conservation project at a farm or regional level in traditional societies, where marginal agriculture is normally practiced. Identification and examination of main obstacles in this system are critical to soil conservation projects.

Figure 1.1 suggests that the central point in soil conservation is to understand farmers' behavior with respect to soil degradation. The diagram includes physical attributes of farm land in relation to erosion risk; farm factors of production, such as capital and labor available for conservation practices; farmers' perception of soil degradation; and the role of market and government institutions, as regulators of specific trends in land use and agricultural practices

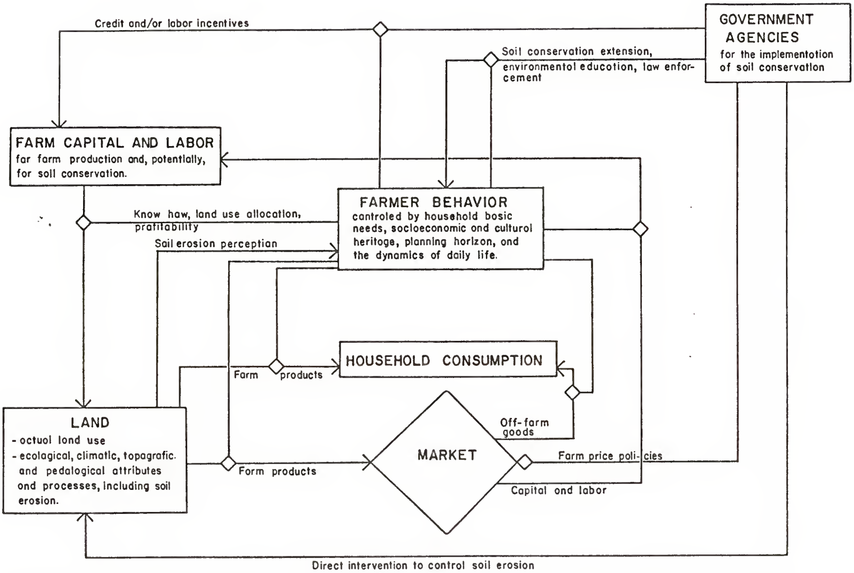
GOVERNMENT AGENCIES
for the implementation of soil conservation
Credit and/or labor incentives
Soil conservation extension, environmental education, law enforcement
FARM CAPITAL AND LABOR
for farm production and, potentially, for soil conservation.
FARMER BEHAVIOR
controled by household basic needs, socioeconomic and cultural heritage, planning horizon, and the dynamics of daily life.
Know how, land use allocation, profitability
Soil erosion perception
HOUSEHOLD CONSUMPTION
Farm products
Off-farm goods
MARKET
LAND
- actual land use
- ecological, climatic, topografic. and pedalogical attributes and processes, including soil erosion.
Farm products
Farm price policies
Capital and labor
Direct intervention to control soil erosion

Figure 1.1. Main components and flows affecting the planning of soil conservation in Las Cuevas.

affecting soil management and conservation. The present study hypothesized particular obstacles in the soil conservation planning of Las Cuevas watershed in the Dominican Republic. The central aspects of these bottlenecks are land attributes in relation to erosion risk; cropping systems and land cover in relation to soil losses; farmers' perception of erosion; farmers' economic performance and its relationship to the erosive ranking of existing farming systems; and the profitability to farmers of adopting conservation practices.

Las Cuevas has been defined by the Dominican Government as a watershed of high priority in terms of soil conservation needs, but no study has been conducted to provide the bases for appropriate conservation planning. Las Cuevas is used as a laboratory, but the methodology and findings are potentially applicable to similar watersheds in the Caribbean and Latin America.

The present study attempts (1) to evaluate the spatial distribution of selected factors affecting soil erosion potential; (2) to propose an appropriate subregionalization of the watershed for purposes of soil conservation planning; (3) to verify the usefulness of the proposed subregionalization for farm level conservation planning; (4) to evaluate the actual response of the farmers through land use and economic performance in relation to the spatial distribution of erosion potential and land capability in their farms; (5) to examine the effect of selected farm attributes and farmer socioeconomic factors as predictors of soil erosion perception and soil conservation intentions by farmers; and (6) to evaluate the private profitability of the adoption of soil conservation practices by individual farmers in a decision year.

Study Region

The Dominican Republic

The Dominican Republic, covering 48,442 km^2, occupies the eastern two thirds of the island of Hispaniola (Figure 1.2). Its Trade Wind location, insularity and relatively small area influence the general climate patterns and the presence of hurricanes. However, the physiographic complexity of the Dominican Republic adds considerable heterogeneity and variability to local climatic regimes. Four major mountain ranges, with three intervening valleys, trend northwest-southeast. The three valleys, with highly productive soils, particularly the Cibao, are the major commercial agricultural regions in the country. Subsistence, mixed and some commercial agriculture also are practiced along most of the flanks of the four mountain ranges which usually have poor, shallow soils.

The amount and distribution of rainfall plays a very important role influencing agricultural crop production in these rainfed farm areas. Rainfall varies sharply in the country from 300mm in the southwest to 2750 mm in the northeast. The dry season usually occurs from December to March although the Northern Mountain Range is wettest from November to January, due to the strengthening of the Trade Winds (Hartshorn et al., 1981). The rainy season extends normally from May to November, with possible occurrences of hurricanes that bring very strong winds and heavy rains.

The population of the Dominican Republic in 1981 was estimated as 5,700,000 with an average density of 110 inhabitants per km^2. However, if only the good agricultural land is taken into account, the

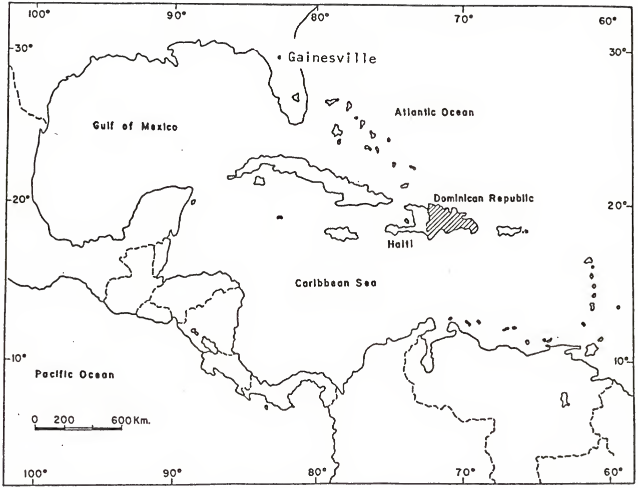

Figure 1.2. Location of the Dominican Republic in the Caribbean.

density increases to 267 inhabitants per km^2 (Perez, 1984). The estimated rate of population growth is about 3% which is not much less than the growth rate of the Gross Domestic Product estimated at 4%, the minimum required to meet the domestic demand for food.

Today, the Dominican Republic is characterized by high rates of urban and rural unemployment, low productivity, high rates of population growth, high proportion of malnutrition, increasing food imports, high rates of land concentration, wide socioeconomic inequalities, increasing environmental problems and large inter-regional inequalities (Perez, 1984; World Bank, 1980; Espinal, 1983; Hartshorn et al., 1981). Furthermore, the economic growth during the last decade was confined to a relatively small segment of the urban population, leaving the majority of urban dwellers and the rural population unaffected or even worse off than before (World Bank, 1980).

Farmers and rural people in general have profited least from development in the Dominican Republic, even though the agricultural sector is the largest employer. The rural poor are poorer than the urban poor; they have higher mortality and illiteracy rates for all ages (Quesada, 1981). Nearly 70% of all farms are less than 5 ha in size, yet these small farms occupy less than 14% of the country's farmland. On the other hand, 3% of the farms exceed 50 ha, but these large farms occupy over half of the national farmland (Hartshorn et al., 1981). In general, large landholders plant cash crops for export, such as sugarcane and coffee, or raise cattle, while small farmers cultivate food crops, such as beans, pigeon peas and cassava.

The income distribution in rural areas shows that over one-third of the population falls into the lowest category, with an income under RD$ 20.00 per month, which is below the RD$ 22.00 rural poverty level (Perez, 1984).[1] Within the spectrum of Dominican farmers, those cultivating marginal and submarginal lands along the mountain flanks are the ones facing critical conditions. They not only have the lowest income and poverty levels but also farm lands having the highest rates of soil exhaustion and erosion due to prevailing agronomic practices. Increasing land degradation is threatening their survival.

Although productivity is low, the agricultural sector has played, and will continue to play, the most important role in the economic development of the country. The structure and performance of the economy is related closely to the agricultural sector. Development efforts in the agricultural sector have to be directed not only to increase productivity and market efficiency but also to manage the natural resource base.

There is no explicit public environmental or resource management policy in the country. Public and private developers have cared very little about the environment; short and long run strategies for rational use of natural resources are almost absent.

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[1] The rate of exchange in 1984 was RD$ 2.80 per dollar.

Las Cuevas Watershed

Physiographic profile

Las Cuevas watershed, covering some 600 km^2, is located in southwestern Dominican Republic (Figure 1.3). Las Cuevas river flows west along the south flank of the Central Mountain Range to the confluence with the Yaque del Sur river, the second largest in the Dominican Republic. Elevations within the watershed vary between 330 and 2650 meters above sea level. Most high elevations are characterized by very steep slopes underlain by permeable to semipermeable volcanic, metamorphic and sedimentary rocks (Antonini et al., 1981). Lowlands and high plateaus cover only 13% of the watershed and are underlain by permeable sedimentary and metamorphic rocks (Antonini et al., 1981). The remaining area, about 7%, consists of floodplains and recent terraces along the entrenched course of the Las Cuevas river.

The range of elevations determines to a great extent the variation of bioclimatic conditions within the region. Four life zones (Holdridge, 1964) are identified; average humidity increases from west to east (Figure 1.4). The western 12% of the watershed has Dry Subtropical Forest conditions with 750 mm of mean annual rainfall and average temperature of 24.5°C. The presence of floodplains and terraces in this life zone has favored a relatively intensive commercial agriculture under irrigation. This is the oldest agricultural area in the watershed. Rice, beans and peanuts are the most common crops. Most of the surrounding hills, rolling lands and high terraces, are still covered by natural vegetation and utilized as

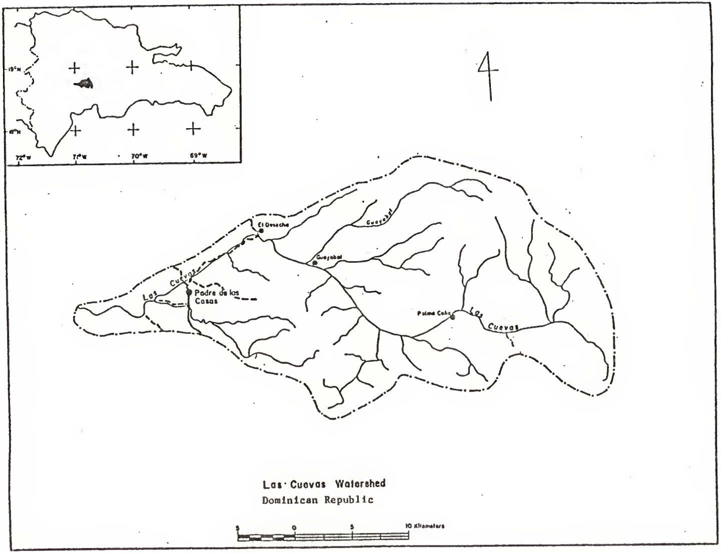

Figure 1.3. Las Cuevas watershed, Dominican Republic.

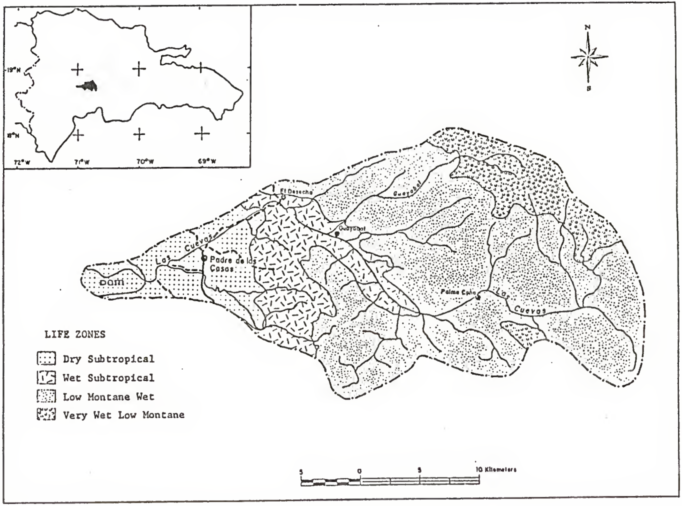

Figure 1.4. Life zones in Las Cuevas.

sources of firewood and/or grazing lands for cattle in the rainy seasons. Natural vegetation is composed mainly of shrubs widely spaced whose more common species include Acacia farnesiana ("cambron," Mimosaceae), Phyllostylon brasiliense ("baitoa," Ulmaceae), Acacia scleroxyla ("candelon"), Bursera simaruba ("almacigo"), Guaiacum officinale ("guayacan"), "candelon," "baya honda," and "apargata." Padre de Las Casas, the largest town in the watershed, with about 10,000 people, is located in this life zone.

Dry conditions decrease eastward with higher elevations. Subtropical Moist Forest conditions prevail and cover about 10 percent of the basin. Mean annual evapotranspiration is about 20% less than mean annual precipitation. The relief in this life zone includes rolling lands with moderate to steep slopes. Coffee, plantain, cassava, beans and other subsistence crops are grown. Some natural and heterogeneous vegetation is found and tree species more commonly consist of P. glaucum ("caracoli"), Tetragastris balsamifera ("almacey"), Anacardium occidentale ("cajuil"), Pithecellobium berteroanun ("corbano"), Roystonea regia ("palma real") and Genipa americana ("jagua"). Mangifera indica ("mango") occasionally is used as a fruit and shade tree.

Subtropical Lower Montane Forest characteristics are present in about 60% of the watershed. Mean annual rainfall is more than 20% greater than annual evapotranspiration. Steep to very steep slopes are very common. Rainfed multiple cropping is practiced extensively and consists of associations of red beans, pigeon peas, corn and cassava. Land rotations occur as part of this shifting cultivation and fallow cover includes Melinis minutiflora ("yaragua"). Coffee and plantain are planted in some places. Natural vegetation still is present, mainly in the form of isolated trees and few continuous patches of forest at the more inaccessible higher elevation. Common tree species are Junipreus gracilor ("sabina"), Syzygium jambos ("pomo"), Prunus occidentalis ("almendro"), Chrysophyllum cainito ("caimito"), Pinus occidentalis ("pino"), Spondias purpurea ("jobo") and Nectandra antillana ("cigua").

About 13% of the watershed in the northeast, close to the drainage divide, is characterized by Subtropical Montane Wet Forest conditions. It is the most humid area in the watershed and freezing temperatures occur regularly in the first months of the year. Slopes vary from steep to very steep. Some land is sporadically cultivated with beans and the rest either is abandoned land with fallow pasture or open low height stands of Pinus occidentalis. Panicum maximum ("yerba de guinea"), Ludwigia erecta hara ("yerba de jicotea") and Melinis minutiflora ("yaragua") are the most common grasses.

Development and environmental profile

There were 19,360 people living in the region in 1960 and by 1970 the population had increased to about 26,000 (Espinal, 1983). The 1981 census indicated that approximately 31,000 inhabitants were living in the watershed. Most people are agriculturalists who live in small towns and hamlets along some river terraces or in the hills adjoining the Las Cuevas river and its tributaries. Padre de Las Casas and Guayabal are the two towns with some merchant retail activity.

Las Cuevas represents one of the most backward areas of the country. General human welfare is characterized by low income levels (Espinal, 1983), poor nutrition (Bruce, 1984; Mancebo, 1984), high rates of illiteracy, poor communications, high birth and death rates, and inadequate sanitary conditions (Montanez, 1983). All these factors, along with a very uneven pattern of land ownership (Montanez, 1983), have pushed the rural poor to use increasingly steeper and more marginally productive lands as a short-term survival strategy. This process has engendered a rapid degradation of the natural resource base in the last four decades. The negative effects of non selective deforestation and the lack of any land management practices have been extended beyond the region and threaten national development projects, such as the energy and irrigation reservoir of Sabana Yegua located downstream.

A recent environmental profile of the Dominican Republic (Hartshorn et al., 1981) showed Las Cuevas to have the third most severe erosion problem among the country's seven most eroded watersheds. It is estimated that accelerated erosion is dumping millions of tons of sediments into the Sabana Yegua reservoir, shortening its projected life span (Hartshorn et al., 1981). In the region, land degradation is easily observed in the dominance of shallow topsoils, presence of gullies, rills, and landslides, and more frequent water shortages due to the decreasing water-holding capacity of its eroded soils. It is quite apparent that the needs for wise development policies and natural resource management are of interest not only to the region but also to the nation as a whole.

CHAPTER II
LITERATURE REVIEW

Literature on soil erosion and soil conservation has been based mainly on research performed in temperate and agriculturally developed areas, particularly the U.S. Only in the last two decades has growing attention been focused on the magnitude of this problem in those tropical and underdeveloped regions facing the twofold trends of increasing food needs and depleting natural resources.

Given the interdisciplinary nature of the problem, various aspects of the relationships between erosion, sedimentation, land use and soil conservation have been treated by geographers, soil scientists, agricultural economists, as well as by researchers in other disciplines. For the purposes of this review, the major topics may be grouped as follows: (1) qualitative studies of erosion processes *per se*, their features, and their spatial distribution; (2) research concerning the physical factors affecting erosion processes and the prediction of their intensity and dynamics through time and in space; (3) attempts to formulate holistic models of physical and cultural factors affecting soil erosion and soil conservation strategies; (4) experimental studies on measures to control soil erosion; (5) investigations of the behavioral aspects of soil conservation focusing mainly on the economics of controlling soil erosion, as well as farmers' perceptions and attitudes; and (6) relevance of present research literature to the conditions of the Dominican Republic and the Las Cuevas watershed in particular.

Erosion Processes

Soil erosion is defined as the removal of surface material by water or wind (Kirkby and Morgan, 1980). In a broad context soil erosion is one of the three major natural processes of sediment removal and landscape development. The other main processes are mass movement and chemical solution. Each of these is dominant in particular environments and therefore soil erosion is not the main process of denudation in all parts of the world. Geographers, geologists and geomorphologists have done extensive work in this context (Davis, 1899; Strahler, 1964; Gregory and Walling, 1973; Morgan 1979). Their findings help to place soil erosion and soil conservation problems on a geological time scale in a worldwide perspective.

An evolutionary pattern of process dominance is suggested. An uplifted mountain mass is commonly dissected rapidly by rivers into steep-sided valleys where landslides, rockfalls and other types of mass movement are highly effective in widening the valleys and lowering their slope gradients. Rapid mass movements are the dominant processes at this stage, soil erosion and chemical weathering usually play such a subsidiary role to the mass movement until a threshold angle is reached, below which the slopes become stable (Kirkby and Morgan, 1980). The stable angle broadly is related to the properties of the bedrock and soils of the area, and to a lesser extent to rock structures, climate and groundwater conditions.

Once slopes are at gradients which are stable with respect to rapid mass movements, the slower processes of soil erosion and solution become dominant. Where rainfall generally percolates into the soil, it flows slowly within soil and rock pores. As a result, it can be highly effective in dissolving material from the soil and bedrock. This not only lowers the land surface, but also progressively converts bedrock into new soil. When it is happening, solution may be the dominant process of landscape evolution and no catastrophic effects should be expected. Where rainfall cannot infiltrate the soil, but flows over the surface, it travels relatively fast, and is able to carry soil materials away through the hydraulic force of its flow.

Where overland flow is dominant, soil erosion by water is likely to be the main process of denudation and solution a subsidiary one. As large amounts of water can flow over the surface, and exert correspondingly large hydraulic forces, it follows that sediments induced by soil erosion act catastrophically even on low gradients. Severe soil erosion associated with gully incision can initiate mass movements from steepened slopes along the gullies. Such mass movements play what may be an important part in the total sediment removal. From the above explanations suggested by the literature on landscape denudation, it follows that soil erosion by water is a natural process in landscape evolution but the rate at which it occurs, over a specific time and space, may bring about the total removal of the soil and, therefore, inhibit the implementation of feasible strategies for agricultural development in those areas more affected by accelerated soil erosion.

Spatial Variations of Erosion

The spatial variation of erosion processes and forms have been studied by geomorphologists, geographers and soil scientists. There are numerous case studies oriented to map erosion features and their dynamics. Field work, aerial photography, and remote sensing techniques have been used to conduct studies for determining the location and severity of erosion losses (Johannsen and Sanders, 1982). Countries, regions and basins have been the subject of erosion severity mapping.

The definition of erosion categories ranges from those purely qualitative to those increasingly quantitative. Mapping categories also vary according to their inherent objective. They may be descriptive, analytical and/or treatment-oriented, and their instrumental capability depends to a great extent on the scale of analysis. The fact that decisions on soil conservation strategies are made at the farm level usually is not taken into account. Recommendations on soil conservation usually ignore the basic criteria involved at the farm scale where the spatial organization of land use is very important. Although soil erosion mapping is a necessary and useful tool in planning soil conservation strategies of particular areas, this is not enough to help in the implementation of conservation programs. There are also social, cultural and economic factors influencing soil erosion processes and soil conservation success. The spatial variation of soil erosion has to be placed within a holistic and dynamic framework (Rocheleau, 1983).

Physical Factors in the Prediction of Soil Erosion

Researchers have identified several factors as the main determinants of soil erosion. These factors include climate, soil properties, topography, cropping patterns and conservation management practices. They may be grouped under three headings: erosivity; erodibility; and protection. The energy group which includes the potential ability of rainfall and runoff to cause erosion is termed erosivity. The resistance group refers to the suceptibility of the soil to be eroded, that is, the erodibility of the soil which depends upon its physical and chemical properties. The protection group focuses on factors relating to the plant cover. Different plants afford different degrees of protection.

Climate influences erosion processes mainly through rain drop size, rainfall intensity and its seasonal distribution. Theory and experimental work have demonstrated the effect of rainfall energy or momentum on erosion processes (Rose, 1958; Hudson, 1961, 1965; Fournier, 1972). The energy involved in rain drops is responsible for the detachment of soil particles, which then are transported by runoff. Rainfall erosivity commonly is measured by an index based on the kinetic energy of the rain (Laws and Parsons, 1943; Wischmeier and Smith, 1958; Hudson, 1965). To compute the kinetic energy of a storm, a trace of the rainfall from an automatically recording rain gauge is analyzed and the storm period divided into small time increments of uniform intensity. For each time period, knowing the intensity of the rain, the kinetic energy of the rain at that intensity is estimated using derived relationships between kinetic energy and rainfall intensity from previous experimental works.

Although the actual performance of the erosivity index may vary on a worldwide scale, there is no doubt about its sound theoretical bases. The difficulty stands in the lack or low density of recorded data in many areas of the world, particularly in developing countries. However, at the present time, data and research support the evidence of greater erosivity of rainfall in subtropical and tropical environments as compared to temperate zones (Lal et al., 1980).

The rate of soil erosion may be influenced by inherent properties of the soil. Some soils erode more readily than others even when all other factors are the same. This difference, caused by soil properties themselves, is referred to as soil erodibility. Many attempts have been made to determine criteria to evaluate the effects of soil properties on soil losses (Lillard et al., 1941; Peele et al., 1945; Wischmeier and Mannering, 1969). Most erodibility indexes are based on properties affecting soil dispersion, soil aggregation, aggregate stability and the transmission of water. Erodibility varies with soil texture, shear strength, infiltration capacity and organic and chemical content.

Large soil particles are resistant to transport because of the greater force required to entrain them and fine particles are resistant to detachment because of their cohesiveness. The least resistant particles are silts and fine sands. Richter and Negendank (1977) show that soils with 40 to 60% silt are the most erodible ones. Overall, organic matter content is ranked next to particle size distribution as an indicator of erodibility because of its influence on aggregate stability. Soils with less than 2% organic matter can be considered erodible (Evans, 1980).

Many attempts have been made to devise a simple index of erodibility based either on the properties of the soil as determined in the laboratory or in the field, or on the response of the soil to rainfall. A more commonly used index is the K value, which represents the soil loss per unit of kinetic energy in a mean annual maximum 30-minute rainfall intensity (Wischmeier et al., 1971). Estimates of the K value may be made if grain size distribution, organic content, structure and permeability of the soil are known. Although these erodibility indexes attempt to quantify the proneness of a soil to be eroded, they do not account actually for the complex interactions of the physical and chemical properties influencing soil erodibility. However, erodibility indexes are very useful in analyzing the spatial variation of soil risks.

Topographic influences on soil losses depend mainly on both length and steepness of the land. Erosion normally would be expected to increase with slope steepness and slope length as a result of respective increments in velocity and volume of surface runoff. Extensive experimental research (Zingg, 1940; Hudson and Jackson, 1959; Djorovic, 1980) has shown a positive relationship between the rate of soil erosion by water and the length and gradient of the slope.

The effect of plant cover and cropping patterns on soil losses is widely recognized. The percent of plant cover and its distribution during the year are very important in protecting or exposing the soil to accelerated erosion processes. The importance of plant cover in controlling soil erosion is demonstrated by numerous field experiments at both plot and watershed levels (Hudson, 1971; Elwell and Stocking, 1976). The canopy protection of plants and crops not only depends on the type of vegetation, the stand and the quality of growth, but it also varies greatly during annual seasons. Plant cover and management effects, induced by cultural and technological practices, are difficult to evaluate independently because of the combined interrelations. However, they are the most important controllable factors in planning soil conservation strategies.

Although the separate effect of the cited erosion factors is relatively well known, the way in which they interact is still a matter of research and discussion (Rocheleau, 1983). Disagreement also exists about the relative weight of each of these factors in different areas of the world. In this respect, research on tropical and subtropical environments is relatively recent and much has to be learned particularly about the effect of present cropping and management practices on erosion rates.

The prediction of soil erosion rates under different conditions also has been the motive of abundant investigations. Efforts have been made to formulate mathematical models in order to predict erosion intensity and to serve as a means to evaluate soil conservation practices. Models have been developed and tested in experimental plots or watershed studies, each model leaning toward greater emphasis on basic or applied research or on realism of theoretical constructs versus empirical results. While one avenue of research focuses on understanding processes and interactions between the various parts of watersheds as complex systems (Chorley, 1962; Likens et al., 1977), the other major thrust of erosion and sedimentation studies has been to develop empirical predictive equations (Wischmeier and Smith, 1965, 1978).

The more theoretical models have evolved primarily within the academic world, for explanatory purposes, or for application under special conditions where extensive data bases are available. Meanwhile, the vast majority of field data collected on erosion, sedimentation and land use has come from empirical studies designed to derive predictive equations that are a kind of black box of complex processes and interrelations (Rocheleau, 1983). The Universal Soil Loss Equation (USLE) is the best known and most widely used model for empirical prediction of soil losses by sheet and rill erosion on specific sites (Wischmeier and Smith, 1965, 1978). The USLE is the result of multiple regression analyses of more than 10,000 plot-years of data from locations east of the Rocky Mountains in the U.S. It is a parametric model in which soil losses are a function of the interaction among erosivity, erodibility, slope length, slope steepness, cropping patterns and conservation practices. The equation is expressed as follows:

$$A = R.K.L.S.C.P.$$

Where A is annual soil loss per unit area; R is a rainfall erosivity index derived from the cross product of the kinetic energy and the average maximum 30-minute rainfall intensity; K is a soil erodibility index expressing a quantitative description of the inherent erodibility of a particular soil, this index is based on soil texture, organic matter content, structure, and permeability (Wischmeier et al., 1971); L is the slope length factor derived from the slope length, which in turn is defined as the distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur, or to the point where runoff enters a defined channel; S is the slope gradient factor that accounts for the influence of slope steepness on soil losses; C is the cropping management factor that weighs the influence of an annual vegetative cover as compared with the soil losses that could occur under tilled bare soil, other conditions being equal (this factor attempts to include the interrelated effects of cover, crop sequence, productivity level, growing season length, cultural practices, residue management, and rainfall distribution). Finally, P is the erosion control practice factor defined as the ratio of soil loss using the specific practice compared with the soil loss using the up-and-down-hill culture. The erosion control practices usually accounted by this factor are contouring, contour stripcropping, and terracing. Detailed procedures for deriving each of USLE factors are presented by Wischmeier and Smith (1965, 1978).

The USLE was developed primarily to provide a planning tool for conservation technicians; therefore, ease of application was a predominant consideration in its development. The general acceptance of the USLE by both technicians and the scientists has demonstrated the extent to which this technique has been successful as a useful field tool in providing reasonable estimates of soil loss (Mitchell and Bubenzer, 1980). However, the use of the USLE in tropical and subtropical environments has been limited because of the lack of experimental work to calibrate certain parameters of the equation. The need for calibration refers mainly to the C factor. Cropping management practices in those environments substantially differ from those found in temperate zones. Therefore, caution should be exercised in value estimation and extrapolation, when specific cultural and environmental conditions are unknown.

Rocheleau (1983) reported that in northcentral Dominican Republic the USLE over-estimated soil loss measured in a two year period in experimental plots with different cropping management practices. However, her observations may not fully reject the usefulness of the USLE since the purpose of this equation is to estimate average soil losses for a relatively long period, given the calibration of parameters for local conditions. Calibration requires relatively long periods of experimental work, and unfortunately, such long-term records are rarely found in the Dominican Republic or in most other Third World countries.

Some researchers suggest the possibility of establishing "first approximation" of factor values for common situations through sound judgment of field researchers and relatively simple field experiments (Mitchell and Bubenzer, 1980). Although this is not a purely scientific alternative it is a feasible one given the absence of extensive recorded data and the presence of urgent needs for implementing steps toward soil conservation. In this context, it is a wise initial decision for countries in the Third World to rely with caution on some of the findings available from the developed world, and to gradually revise them, as local research is set up and data are produced. This process is almost inevitable, particularly in fields where research is time consuming, as is the case of soil erosion and soil conservation.

It is observed that four of the six USLE parameters are less dependent on human activities under conditions of no conservation practices. Arnoldus (1977) used these four factors, erosivity, erodibility, slope gradient and slope length, to evaluate maximum potential erosion indexes in areas of the U.S. and Morocco, respectively. In the absence of calibrated data for cropping management and conservation practices, this approach seems appropriate for comparative purposes in the analysis of the spatial distribution of erosion potential in a particular region.

Experimental Studies on Soil Erosion Control Measures

From the identification of the factors influencing the rate of soil erosion it follows that measures for soil conservation must be based on covering the soil to protect it from raindrop impact, increasing the infiltration capacity of the soil to reduce runoff, improving the aggregate stability of the soil, and increasing surface roughness to reduce the velocity of runoff. Agricultural engineers, agronomists and ecologists have proposed and tested many soil conservation techniques (Stallings, 1957; Schwab et al., 1966; Hudson, 1971; Suarez de Castro, 1982) that range from agronomic measures through soil management practices and mechanical means.

Agronomic techniques are based on the role of plant cover in reducing erosion. Because of the difference in their density and morphology, plants differ in their effectiveness to protect soil from erosion. Extensive experimental plot studies have shown the influence of different plant covers in determining erosion rates (Conner et al., 1939; Suarez de Castro, 1982; FAO, 1965; Kellman, 1969; Temple, 1972;

Rocheleau, 1983). Generally, short cycle row crops are the least effective and give rise to the more serious erosion problems. This is because of the high percentage of bare ground, particularly during land preparation and early stages of crop growth. Crop relations, cover crops, strip cropping and mulching, among others, are effective agronomic techniques suggested by soil conservation researchers (Hudson, 1971; Wischmeier and Smith, 1965; Williams and Joseph, 1970; Beale et al., 1955; CATIE, 1980; Greenland and Lal, 1975; FAO, 1965; Cooke and Doornkamp, 1974).

Soil management practices to control erosion are aimed at promoting aggregate stability, increasing water retention capacity and improving the cohesiveness of the soil. Application of organic matter and minimum tillage are common soil management practices recommended in the soil conservation literature (FAO, 1977; Hudson, 1971; Fournier, 1972).

Many techniques are available within the group of structures and mechanical field conservation methods (Wischmeier and Smith, 1965; Hudson, 1971; Morgan, 1979; Sheng, 1972). Some of these techniques were practiced by flourishing societies in Latin America before the discovery of America, as is the case of the terraces built by the Incas in Peru. The list of theoretically available techniques includes contouring, terracing, contour bounds, waterways, stabilization structures and windbreaks. Many of these mechanical methods are costly to install and maintain and, therefore, create difficulties for farmers who are not used to these practices.

From this review of the literature on soil conservation techniques, it is concluded that the wide range of theoretical possibilities available is not reflected in the rate of adoption of conservation practices. This reality is clearly evident not only in developing countries but also in developed ones. Without a doubt, institutional and behavioral aspects influencing the willingness of farmers to adopt conservation strategies are as important as the techniques themselves.

Holistic Dynamic Models of Soil Erosion and Soil Conservation

Erosion related models are found in the research literature. A diverse range of models has been formulated, some of them empirically tested, others purely theoretical. According to the researcher's particular disciplinary orientation, they may emphasize hydrology, geomorphology, ecology or rural development (Antonini et al., 1975; Chorley and Haggett, 1967; Chorley and Kennedy, 1971; Hall and Day, 1977). Most of these models have been inspired by systems theory and attempt to serve as analytical and simulation tools for analyzing processes and possible impacts of alternative policies in natural resource management and development projects.

Antonini et al. (1975) developed a model of interactions between land use, erosion and sedimentation in a rugged upland region of the Dominican Republic. This model was formulated in energy language (Odum, 1972) and it is a combination of two energy flow submodels describing land use and water budget impact on reservoir sedimentation. This is a regional model and, therefore, its usefulness is limited when the main concern is how to implement adequate land use and soil conservation policies at the farm level.

Prompted by a similar concern to develop a holistic approach, Rocheleau (1983) attempted to fill the existing vacuum between farming systems and environmental research as well as between farm level and watershed analyses. Regional watershed, microwatershed and farm models were formulated in energy language, incorporating agro-socio-ecological subsystems and land use on field sites in the central uplands of the Dominican Republic. Unfortunately none of these models actually have been simulated and, therefore, their power and validity cannot be evaluated.

The power of this systems methodology is evident but its application in the Third World has been limited by the lack of specific research programs to supply the extensive and operative data that are required for a reliable simulation.

Adoption and Use of Soil Conservation Practices

Investigation of the factors affecting adoption and use of soil conservation practices began in the 1950s in the United States. Sociologists, geographers, economists and environmental psychologists have identified several behavioral factors influencing farmers' attitudes toward soil conservation. These factors include cultural, social and economic aspects. The studies can be grouped into two classes: those concerned with the identification of factors affecting farmers' soil erosion perception and soil conservation adoption, and those focused on the purely economic aspects of soil conservation.

Blase (1960) found that the following factors were statistically significant in explaining reductions in soil loss by adoption of conservation practices: (1) off farm income interpreted as a means to overcome financial constraints; (2) perception of soil erosion as a problem; and (3) ability to borrow funds. These findings imply that economic constraints play an important role in the decision to use effective soil conservation practices.

More recent investigations have expanded the range of variables considered to include personal factors. Carlson et al. (1977), in a 1976 survey of Palouse farmers, found that increasing levels of education, farm size and gross income were moderately associated with a higher number of conservation practices. Earle et al. (1979) derived a linear discriminant function for predicting intentions toward soil conservation of some Australian farmers on the basis of five socioeconomic variables: farm size; perception of soil erosion importance; double cropping practice; farm income; and educational level.

In reviewing research concerning factors affecting the perception of the erosion problem and the adoption of conservation practices, it is found that studies support the role of a variety of economic, physical, personal and institutional factors. However, the effects of these factors have not been studied simultaneously. Furthermore, most of these studies have been carried out in developed countries, where the socioeconomic and cultural setting is substantially different from Third World tropical and subtropical environments. Testing the combined relevance of the mentioned factor in these environments will give insight into the particularities of the problem, and will open the possibilities of infusing new ideas and better planning in local soil conservation programs.

Economics of soil conservation has been the subject of study by American researchers since the 1940s. Four directions of research can be distinguished: (1) studies oriented to evaluate the effect of soil depth on the value of agricultural land; (2) studies concerned with the economic impact of soil erosion on the productivity of the land and/or the quality and quantity of water downstream; (3) investigations oriented to weigh the economic motivation of individual farmers and the society in soil conservation decisions; and (4) research directed to the optimal allocation of land use and conservation practices at the farm or regional level, under factor constraints and soil loss limits.

Ibach (1940) focused on topsoil in the Corn Belt as the critical resource determining value of agricultural land and used pounds of nitrogen per acre in the topsoil as a measure for estimating land values. Englestad et al. (1961) studied the effect of surface soil thickness on corn yields in an experiment of farmer operated fields in the U.S. Their findings support the hypothesis of the inverse relationship between crop yield and topsoil thickness due partly to the amount of soil loss but mainly to the quantity of nitrogen lost. This suggests the possibility of nitrogen substitution through fertilization.

In the same direction Burt (1981) suggests that farmers are unconcerned about soil losses because they can substitute other inputs for soil depth. This observation does not take into account the fact that eroded soil not only suffers from nutrient losses but also from decreasing water retention capacity which in turn decreases yields. Furthermore, it is recognized that when soil losses overcome a critical soil depth, the addition of inputs does not compensate for those losses.

On-site versus off-site effects of erosion also have been the focus of frequent analysis (Gunterman et al., 1955; Swanson and Harshbarger, 1964). On-site effects usually are associated with private interest and off-site damages are associated with the interest of the society. On-site damages primarily take the form of productivity losses caused by the erosion of the most productive top soils. These losses would be reflected in the private net income of the farmers which would be lower than they should be if appropriate soil conservation measures were employed. Off-site sediment damages are defined to include all costs that result from the sediment after it has left the farm site. These damages include, among others, shortening of the economic life of reservoirs; increasing turbidity of rivers which interferes with aquatic life; growing flood costs downstream; and damages to recreational and irrigation facilities.

Advocating a stronger public policy, Gunterman and his associates (1955), point out that off-site sediment damages are far greater than the on-site productivity effects of erosion and, therefore, there is a considerable justification for more aggressive public policies in this area. Swanson and Harshbarger (1964) observed that the central problem in the economics of soil conservation is to balance present with future needs for the soil resource. In the same direction, Narayanan and Swanson (1972) point out that it is necessary to sacrifice farm income in order to reduce sedimentation. This is an important factor in determining public policy with regard to soil loss from farms.

Studying the effects of various soil conservation measures on farmers income in specific soil series of Illinois, Swanson and MacCallum (1969) concluded that there is little incentive for a profit maximizing farmer, even if he plans over a long period of time, to adopt soil conservation practices that would reduce soil losses to a tolerable limit. They added that if limits are to be achieved, the financial incentive to adopt needed conservation practices must be increased substantially. The same conclusion has come up from a large number of studies using linear programing methods, often at the watershed level. These programs have formulated the problem as one of profit maximization, constrained by soil loss tolerance levels (White and Partenheimer, 1980). In general, these studies support the weak private economic incentive hypothesis.

Young et al. (1979) used a simulation model to analyze the long-run incentives for adoption of soil conserving tillage systems in the Palouse. They concluded that if soil conservation researchers develop farming systems that save soil but decrease yields and/or increase costs, while at the same time agricultural scientists as a whole continue making advances that increase yields in spite of topsoil depletion, economic incentives will continue for many years to favor the use of more erosive systems.

Other studies concerning the private profitability of adopting certain conservation practices have not shown consensus. This suggests that private profitability is determined by regional and local conditions of soil properties, cropping patterns and economic factors of production (Mitchell et al., 1980).

There is much to be known about farmers' tolerance of erosion, and new lines of investigation have to be addressed. Despite many research and extension efforts and substantial expenditures by the U.S. Soil Conservation Service, there is little evidence that soil erosion has been curtailed. In developing countries, the task is still more difficult; the lack of public concern and private awareness about the erosion problem and the lack of resources have hindered the development of appropriate research and extension programs to promote locally effective alternatives for soil conservation.

Studies of the private profitability of adopting conservation practices in the context of Latin America are almost absent. Many farmers of upland Latin America are subsistence farmers who have very weak linkages to the market and very low awareness of the soil erosion problem. Modelling the subsistence farmer's soil conservation decision process is a difficult task under such circumstances. However, exploratory findings through case studies can be useful in setting up a basic understanding of the problem.

Simple normative land use allocation models at the farm level and their comparison with actual land use can give insight into the farmers behavior about intrafarm organization of land use and its impact on soil erosion. Other lines of exploratory research can be directed to identify functional relationships between soil depth and crop yields in particular regions and how this relationship may influence farmers' behavior with respect to soil erosion control. The last approach is used in this study of the Las Cuevas farmers' behavior related to soil conservation.

Relevance of Research Literature for the Study Region

Given the tremendous variability of the erosion process, research must be done both vertically and horizontally. More in depth experimental work should be carried out to achieve a thorough understanding of the nature of the interaction among erosion factors . Worldwide study of soil erosion is needed to embrace the greater variety of environments and detect the degree of generalization of certain processes. General causative factors of soil erosion in temperate zones are the same in tropical regions, however, the level of soil erosion, the weight and dynamics of each erosion factor, and the overall interaction are still matters to be investigated in tropical environments. It has often been stated that on a global scale the hazards of water-induced soil erosion are restricted mostly to the regions between 40° north and 40° south latitude (Hudson, 1971). In addition, some conditions favoring high rates of soil loss in the tropics have been mentioned. These conditions include (1) high intensity of rainfall, (2) high rates of overland flow from adjacent uplands, (3) poorly structured soils with low infiltration rates, (4) slopes from moderate to high steepness, (5) long slope length, (6) tillage and planting directed along the prevailing slopes, and (7) sparse vegetative cover with insufficient protective organic residue (El-Swaify et al., 1982). Testing some of these conditions in the study region was one concern and in that respect the soil sampling and farm survey were revealing.

Although the USLE has been used in tropical regions (Roose, 1977; Hurni, 1981) it has yet to be fully tested for applicability in these environments. This is due partly to the lack of expanded data and the rigorous requirement of basing its use on site-specific long-term data for component parameters (Wischmeier, 1976). Unfortunately, no alternative comprehensive models are available for soil loss predictions in the tropics. Until research can expand the data base, extrapolation of the formulas provides the best information available, but their limitations must be recognized (El-Swaify et al., 1982). Individual causative parameters in the USLE equation or a sound combination of them can be used for relative comparisons of the spatial distribution of erosion risk in a particular region. In the absence of calibrated values for the C factor, this last approach was used by Arnoldus (1977) to determine maximum potential average of annual soil losses in Morocco. A similar procedure was applied in this study for weighing relative spatial variability of erosion potential within Las Cuevas watershed.

There are no direct measures about soil losses in the study region as related to specific land uses or crop rotations. However, data from Rocheleau (1983) and other studies in tropical America (Table 2.1) give an idea concerning the order of magnitude of soil erosion under common plant covers and crop rotations, some of which are found also in Las Cuevas watershed. These data confirm the findings of other researchers about the effect of crop types, canopy characteristics, and growth habits on soil losses. But manifestations of these characteristics are extremely dependent on the existing farming systems which in turn influence crop rotations, planting

Table 2.1. Soil losses under different land covers and cropping systems in the tropics, as reported by different sources.

Vegetation Source	Slope %	Soil texture	Annual Rainfall (mm)	Conservation Practice *	Soil Loss (Tons/Ha/Yr)	**
Old coffee	35	Silty loam	2645	1	1.9	1
New coffee	38	Silty loam	2645	1	1.8	1
Pigeon pea, sweet potato	44	Sandy Loam	1530	2	6.2	1
Pigeon pea, sweet potato	46	Sandy loam	1530	3	7.4	1
Cassava, corn red beans	34	Sandy loam	1530	2	25.4	1
Cassava, corn read bens	34	Sandy loam	1530	1	43.5	1
Pasture	25	Loamy sand	1530	1	0.25	1
Pine forest	34	Sandy loam	1530	1	0.10	1
Pine forest	28	Sandy loam	1530	1	0.15	1
Pasture	25	Sandy loam	1530	1	0.25	1
Sisal, sweet potato	34	Loam	1250	1	22.00	1
Sisal	32	Loam	1250	1	21.9	1
Pasture	35	Loam	1250	1	1.5	1
Pasture	31	Loam	1250	1	1.6	1
Yuca	39	Sandy loam	1250	1	16.3	1
Pine forest	30	Sandy Loam	1250	1	0.1	1
Clean-tilled-fallow	--	----	----	1	312.4	2
Pasture	--	----	----	1	6.7	2
Shaded coffee	--	----	----	1	0.1	2
Forest	12	----	1300	1	0.001	3
Pasture	12	----	1300	1	1.0	3
Non shaded coffee	12	----	1300	1	1.4	3
Cotton	12	----	1300	1	36.0	3
Natural bush	10	----	1300	1	0.2	4
Peanuts	10	----	1300	1	6.9	4
Sorghum	10	----	1300	1	8.4	4
Maize	10	----	1300	1	10.3	4
Cassava	10	----	----	1	12.9	5
Cassava, beans	10	----	----	1	17.7	5
Cassava	--	----	----	1	43.0	6
Cassava	--	----	----	4	11.0	6
Clean-tilled-fallow	--	----	----	1	375.0	7
Field crops	--	----	----	1	100.0	7
Field crops	--	----	----	2	39.0	7

Table 2.1--continued.

Vegetation Source	Slope %	Soil texture	Annual Rainfall (mm)	Conservation Practice *	Soil Loss (Tons/Ha/Yr)	**
Field crops	--	----	----	5	27.0	7
Field crops	--	----	----	6	17.0	7
Field crops	--	----	----	7	10.0	7
Fertilized pasture	--	----	----	1	5.0	7
Dense forest	--	----	----	1	0.5	7
Clean-tilled-fallow	--	----	----	1	253.0	8
Field crops	--	----	----	1	15.2	9
Field crops	--	----	----	8	1.0	9
Pasture	--	----	----	1	4.0	9
Fertilized pasture	--	----	----	1	1.5	9

*Conservation practices are coded as follow: 1, conventional tillage; 2, hillside tillage; 3, hillside tillage and minimum tillage; 4, mulching of maize; 5, hillside ditches and contours; 6, bench terraces; 7, mix of practices; 8, mixed mulching.

**Information sources are coded as follows: 1, Rocheleau (1983),experiments carried out in the Central Mountain Range of the Dominican Republic during a 1.8 year period; 2, Suarez de Castro (1954), experiments carried out in the coffee area of Chinchina, Colombia, during a 5-year period; 3, Marques (1951), experiments carried out in Sao Paulo State, Brasil, during a 2-year period; 4, experiments carried out in Senegal and reported by Rocheleau (1983) as taken from Charreau (1972), length of experimental period was not specified; 5, Leesberg (1981), experiments carried out in the Central Mountain Range (Sierra) of the Dominican Republic during a one year period; 6, Howeler and Dadavid (1982), experiments carried out in the Central Mountain Rainge (Sierra) of the Dominican Republic during a 10-month period; 7, Sheng and Michaelson (1973), experiments in the Jamaican hills, length of the experimental period was not specified; 8, Smith and Abruna (1955), experiments in Puerto Rico and reported by Rocheleau (1983), experimental period was not specified; 9, experiments in Puerto Rico reported by Rocheleau (1983), experimental period was not specified.

density, crop associations and management of ground-covering residue. Therefore, any attempt to design the basis for feasible conservation programs has to be done on the best awareness of the land use and farming systems in the region. Emphasis on this approach has been followed recently by Paulet (1977) and Blomer (1983) in the Dominican Republic.

A soil erosion related analysis of the farming systems in the study region was carried out using the information collected by the author and the other participants in the Integrated Training and Research Program in Natural Resources Management for The Dominican Republic (Antonini et al., 1981; Espinal, 1983; Nunez, 1983; Reynoso, 1983; Mancebo, 1984; Nova, 1984).

The relevance of the present literature regarding farmers' perception of soil erosion and their attitudes toward soil conservation is a matter of testing in this study. The author knows of no other studies in Latin America focusing on these aspects. Although Suarez de Castro (1982) mentions general factors that may influence farmers' attitudes, no empirical and systematic investigations are presented to support this hypothesis.

Blomer (1983) reported that informal interviews with farmers who had adopted recently soil conservation practices showed that they perceived the erosion problem in their own words, but they only adopted conservation practices because of the persuasion of the Plan Sierra extension agents in this region of the Dominican Republic. At the same time, the interviews showed that some non-adopters also had knowledge of the erosion process which suggests the fact that knowledge and perception of the problem are not sufficient to prompt adoption of soil conservation measures. How these preliminary findings from the Dominican Republic and those taken from temperate zones fit into the characteristics of the Las Cuevas farmers was another question to be answered by this study.

Most studies investigating the private profitability of soil conservation practices conclude that, in general, there is a lack of economic incentive in the planing horizon of the farmer for adopting such practices. This also may be the case of a small farmer in a developing country who does not have capital available to invest in such programs. While in a developed country farmers may have capital to share and invest with government institutions, small subsistence farmers normally can not do so. Thus, the more likely situation for a small farmer in an upland rainfed area is a lack of economic incentive and a lack of resources to invest in a conservation enterprise which is sealed by uncertainty.

Furthermore, erosion control measures appropriate for large farms are often completely irrelevant for small ones; small farmers are likely to continue mixed cropping and shifting cultivation (Dumsday and Flinn, 1977). Conservation systems for the small holder more likely need to rely on the spatial organization of the crops within the farm, crop selection, mulching, cultivation practices and the timing of these operations for their success, as opposed to the use of mechanically constructed erosion control measures.

The Land and Water Department (LWD) of the State Secretariat of Agriculture (SEA) in the Dominican Republic has tried to implement construction of terraces in some areas of Las Cuevas. While some success in farmers' acceptance is observed in a small area of the watershed, in most cases terrace maintenance has been a failure. Undoubtedly, cultural, educational and economic constraints impede the permanence of these structures. Instead of dealing with that culturally estranged alternative, it seems advisable to try more simple approaches such as the ones mentioned above. However, this has not been the orientation of the LWD in the Las Cuevas region.

LWD efforts have been focused mainly on the construction of structures, like terraces and bench terraces following the recommendations derived from the application of the USLE to specific farm fields. After eight years of work in this direction, only fifty-two out of more than two thousand farmers in the region have accepted the construction of structures in some of their fields. In almost all cases construction work has been done by technicians and workers of the LWD, with little or no participation by the farmers. In most cases, farm operator intervention has been reduced to expression of acceptance about building up certain structures, from a narrow range of alternatives that have been presented to him. In these circumstances, the absence of structure maintenance has been one of the more evident results. Some farmers have destroyed these terraces and returned to the old situation which is sometimes worse in terms of soil productivity and erosion losses.

CHAPTER III
METHODOLOGY

Spatial Distribution of Factors Affecting Soil Erosion Potential

Maximum erosion potential for specific sites is defined by Arnoldus (1977) as the maximum amount of annual erosion that would be produced under continuously bare soil. Thus, erosion potential is a function of a set of relative permanent factors given by natural conditions. For a specific site, these factors include the erosivity of the rainfall, the erodibility of the soil and the ground topography expressed mainly through its slope gradient and slope length. Analysis of the spatial distribution of these factors was required to give insight about the variation of potential erosion hazards in the watershed.

One primary and two secondary sources provided the basic data for this analysis: (1) sample soil survey of Las Cuevas watershed, carried out within the joint program U.F.-SEA (Ledesma, 1983), (2) Dominican Republic erosivity map published by SEA-IICA (1982) and (3) topographic maps at scale 1:50,000 (U.S. Army, 1966).

The design of the soil survey is described by Ledesma (1983) as a two-stage sampling procedure. The watershed was covered by a grid containing 2312 cells of 0.25 km^2 each. Each cell was divided into 25 sites of 100 m^2 and one site was drawn randomly from each of the randomly selected cells. Figure 3.1 shows the distribution of sampled sites in the watershed. Surface information and soil samples were

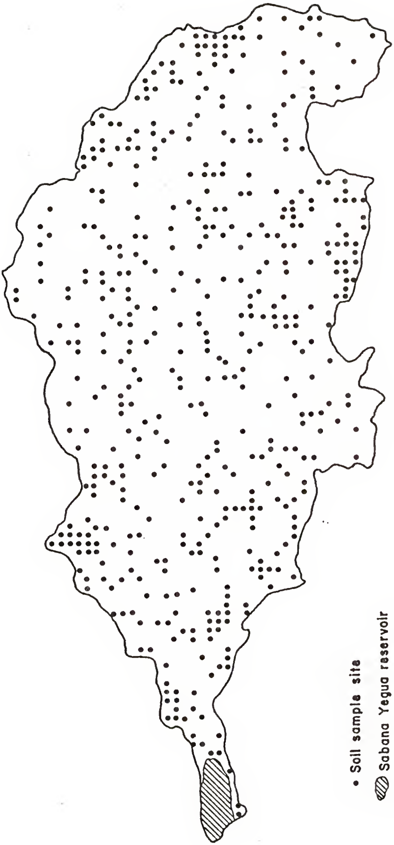

Figure 3.1. Location of soil sample sites.

taken from each selected site. Laboratory analysis of these soil samples was carried out by the SEA Soil Testing Laboratory in San Cristobal, Dominican Republic. Spatially coded field and laboratory data from this survey were the basis for evaluating the distribution of erosion factors in the watershed. Evaluation of erosion factors was conducted for each site included in the soil survey. A brief description of the way in which each site factor value was estimated is presented below.

Rainfall erosivity was estimated by photographically enlarging the national erosivity map to permit transposing the isoerodent lines covering the Las Cuevas region to a 1:50,000 base map. Simple spatial interpolation was used to assign a rainfall erosivity value to the soil sample sites.

An approximation of soil erodibility for each topsoil sample was estimated as a function of organic matter and soil separates, using the standard Wischmeier diagram (1976) that is shown in Appendix 1. Data for soil separate proportions and organic matter content were available from the laboratory analysis. Slope gradient for each sample site was taken directly from the field survey records. Slope length was not available from the soil survey and was difficult to assess from the 1:50,000 topographic maps; this factor was held constant since the cells were equal in size. This assumption was made knowing that possible underestimation or overestimation of erosion potential for specific cells would not affect significantly the general trend of spatial variations in the watershed. The farm survey conducted later supported this assumption.

Once the values for each factor affecting erosion potential were estimated for all sampled sites, spatial variation was analyzed using a computer assisted mapping program to plot slope, erosivity of rainfall, organic matter content, silt content, and overall erodibility of soil. Mapping was carried out using SYMAP routines. In addition to spatial analysis, the above variables were checked for possible correlations with altitude, an independent variable and one easy to measure in the field or on the maps.

Intrawatershed Erosion Risk Units

Applying the erosion potential index concept (Wischmeier, 1975; Arnoldus, 1977), the more stable factors in the USLE were selected to generate erosion potential values for the sampled sites. Maximum erosion potential for a specific site is expressed as

$$A=RKLS$$

where A is annual soil loss in tons per hectare; R is rainfall erosivity index expressed in tons per hectare; K is soil erodibility index per unit of erosivity; and LS is slope steepness and length index, or topographic factor.

The above equation is equivalent to assigning the value of 1 to factors C and P, respectively, in the original USLE equation. This means that A expresses the total amount of soil losses that would occur in absence of any soil cover (C=1) and soil conservation practices (P=1). Therefore, erosion potential as defined here, and previously by Arnoldus (1977) and Wischmeier (1975), is a function of those USLE factors relatively independent of human activities. Since experimental calibration does not exist for the particular cropping systems in the region, this partial use of the USLE accounts for the very basic natural conditions affecting erosion potential in the presence of a very low portion of land cover.

Once erosion potential was estimated for each sampled site, an erosion potential map was generated using the Surface II Graphic System (Sampson, 1978). Three categories of erosion potential were defined according to the optimal stratification rule (Scheaffer et al., 1979). Thus, areas of moderate, high and very high erosion risk were identified in the watershed. These areas are proposed as intermediate spatial units for soil conservation planning in the watershed. The practical relevance of these units for soil conservation planning at farm level is evaluated through the analysis of a sample of farms and their farmers, which is described in the next section.

Actual Farmers' Behavior Regarding Erosion Risk

The literature review shows the overwhelming influence of land cover and cropping patterns in determining actual rates of erosion. Short cycle crops, in general, have a higher erosive ranking than permanent tree crops. They differ in the percentage and annual distribution of ground cover which explains most of the variations of erosion rates among cropping systems.

Land cover and cropping patterns, obviously, are very dependent on farmers attitudes towards the use and management of land. Actual farmers' decisions about what to do with the land and how to do it are very complex in traditional societies and they deserve particular attention. This topic was not a main concern in this study, but an attempt was made to answer the following questions: what is the use that farmers are giving to the land, how do they manage the land, and what are the implications of their behavior with respect to soil degradation?

The analytical approach used a stratified sample of farms and farmers in the watershed. The erosion potential units defined previously served to delimit the three strata. Visits to farms in the sample and interviews with their respective farmers were required to record intrafarm spatial organization of land use, recent farm history, presence of erosion features, soil depth, farmers' erosion perception and farmers' economic performance.

In order to draw the sample, the following tasks were carried out: first, a 1:10,000-scale map of farm distribution was compiled from data collected by the Dominican Cadastral Office in the period 1975-1978, and an identification number was assigned to each farm as a sample unit; second, the boundaries of the erosion potential units were traced on the farm map in order to delineate the sampling strata; third, a list of farmers and their respective farms was compiled for each stratum; fourth, the sample size was selected and proportionally allocated to each of the three erosion risk units using the standard method for stratified random sampling (Scheaffer et al., 1979), as is detailed in Appendix 2.

A minimum of 194 farms was required for statistical purposes. Actually, 210 farms were sampled by addition of a random sub-sample of farmers that had carried out some conservation practices under the supervision of the LWD. The objective of this subsample will be explained later.

Two types of data were collected: farm field data and farmer interview questionnaire (Appendix 3). The farm field data was recorded when each farm was visited. This information refers mainly to land cover, slope gradient and length, soil depth and texture of topsoil and presence of erosion features. The farm field data was compiled by farm plots. Each plot was defined as that part or portion of a farm with a particular use.

The farmer interview data included two parts. The first was common to all farmers and consisted of questions directed to (1) confirm the location and identification of farms and farmers, (2) collect data about recent history of the farm, (3) identify the present crop rotations and land management, and (4) evaluate environmental perception of farmers. The second part of the interview was concerned with the farmers' economic performance on each plot during 1983. Specific questions were designed for each crop or cropping patterns to assess production costs, crop yields and crop prices.

The original farm and farmers' questionnaires were tested in the region during the first three weeks of December 1983 and, after some modifications, the final versions were condensed into one questionnaire (Appendix 3). Field work was carried out continuously from January until May of 1984. Visits to sampled farms were made riding mule, motorcycle, and car when it was possible. Local individuals assisted in locating and identifying sampled farms and farmers. All information was tabulated, coded and recorded on computer cards.

Overall Relevance of Proposed Intrawatershed Subregionalization

The validity of the erosion risk areas, as intermediate spatial planning units, was tested using the sample data. The ideal planning unit would be that in which its homogeneity was given not only in terms of erosion factors, but also in farmers' economic performance. The relevance of erosion risk units for broader planning was evaluated by testing homogeneity of erosion and economic aspects.

The Duncan statistical procedure (Kramer, 1956) was used to test differences among the three areas in relation to average field slope gradient, average field slope length, average production costs and average net returns per tarea. Chi-square homogeneity and association tests also were performed to examine differences among the three areas with respect to the presence of erosion features such as landslides, gullies and rills.

Farmers' Response to Erosion Risk Conditions

The actual response of the farmers to the erosion risk conditions on their farms was assessed by analyzing the relationship between land use or land cover variations within the farm and land capability variations. Farms were classified according to the number of farm plots, and association analysis was carried out to test possible relationships between plot characteristics and the typical land use expressed through crop rotations. Particular plot conditions such as slope gradient and soil depth, as well as overall plot conditions, using land capability classes (Klingebiel, 1958), were tested against the actual land use and/or land cover. This procedure permitted the evaluation of the degree of discrepancy between recommended land use from the soil conservation point of view and the actual land use practiced by the farmers.

Crop management practices related to erosion were analyzed with respect to variations of erosion risk during the year. Erosion risk varies according to rainfall distribution. Particular crop and land management practices may accentuate or decrease actual rates of erosion. The agricultural calendar and the nature of the management practices for typical crop rotations, and their relationships with annual variations of erosion risk were analyzed to examine what were farmers doing contrary to or in favor of soil conservation.

Farmers' Perception of Soil Erosion

The literature points out that farmers' perception of erosion plays an important role in their attitudes toward adoption of soil conservation practices. Different levels of perception may influence different levels of motivation for the acceptance and maintenance of such practices. A study of Las Cuevas farmers' perception of the soil erosion problem was considered important for two reasons: to weigh farmers' response to soil conservation diffusion efforts in the region, and to identify possible groups of farmers according to their erosion perception with the purpose of being targeted by different strategies of soil conservation extension and environmental education.

Two main questions were addressed in this analysis: Do farmers in Las Cuevas perceive erosion as an important problem? Is there any relationship between farmers' perception of erosion on their farms and some of their personal attributes, as well as their farm characteristics? The first question was evaluated using simple frequency analysis to assess the degree to which farmers include erosion within their set of priority problems. The answer to the second question was approached testing the capability of a discriminant function to predict farmers' perception of erosion on the basis of their farm and personal characteristics. The hypothesized function may be conceptualized as follows: F = f (farmer socioeconomic attributes and farm erosion related variables).

It was hypothesized that the simplest form of F, a simple linear model, would be applied. That is,

$$Fi=b0+b1X1i+b2X2i+\ldots+bpXpi+c1Z1i+c2Z2i+\ldots+cpZpi$$

where Fi is the posterior odds (likelihood) of an individual belonging to erosion perception group i, as compared to other groups, given a set of variables; Xpi is the value of the pth socioeconomic variable of individual belonging to group i, according to his level of perception of the soil erosion problem; Zpi is the value of pth variable related to erosion in the farm of an individual belonging to group i, according to his level of perception of the erosion problem; bp is a weighting coefficient for the pth variable.

The relationship between Fi and the selected farmer and farm variables Xpi may be explained also through the use of a linear discriminant function Di as Cooley and Lohnes (1971) have pointed out. Thus,

$$\log F_i = \log(\text{Prior odds}) + D_i \text{ and } D_i = d_iZ_{1i} + d_2Z_{2i} + \ldots + d_pZ_{3i}$$

where D_i is the ith individual farmer discriminant score; d_p is a standardized weighting coefficient, and Z_{pi} is the standardized value of the pth discriminating variable for the ith individual farmer.

The hypothesized characteristics of the farmers and their farms related to their erosion perception were age, level of formal education, size of the farm, average annual net revenue per tarea, average slope gradient of the farm, presence of gullies and depth of solum. The influence of some of the variables has been tested positively in Australia and North America (Earle et al., 1979; Kasal, 1970), but their relevance in environments such as the study region were unknown.

Evaluating Private Profitability of Soil Conservation Adoption

Farmers' perception of erosion as a problem is not enough to motivate them to actually adopt soil conservation practices. The adoption of soil conservation practices normally requires knowledge and utilization of more resources than those needed for cropping using traditional erosive practices. Both, the knowledge and the actual application of it, imply use of capital and labor. Capital is particularly scarce in areas such as Las Cuevas and this makes the task still more difficult.

There is an implicit acceptance that investing in the process of learning and teaching soil conservation must be assumed by the government through specific research and extension agencies. It is argued that this investment is justified on the benefits derived by society in obtaining better water quality, sustained soil productivity and lower siltation rates of hydroelectrical facilities. However, the existence of specialized public soil conservation agencies has not guaranteed wider adoption of soil conservation, even in the United States, where large sums have been spent in research, extension and environmental education.

It is quite apparent that in addition to cultural constraints, obstacles for soil conservation are raised by the scarcity of resources needed to adopt and maintain such practices, and mainly by farmers' uncertainty about private profitability of carrying them out within their planning horizon. An examination of the last two aspects was attempted in the case of Las Cuevas. General theoretical considerations supported by available empirical data were the main input in the analysis.

Annual net returns from farming were examined against annual costs of production, and capital availability was assumed to be closely related to these levels. Furthermore, farmers were asked about the likelihood of carrying out soil conservation on their own (Appendix 3) with technical assistance of the LWD. Frequency analysis of these answers permitted some preliminary findings.

Private profitability of soil conservation adoption was examined by means of an erosion damage function. This method compares traditional farming and conservation practices, within a dynamic analysis, treating the conservation adoption year as a variable. The analysis assumes that the farmer has been using traditional, conventional tillage and now evaluates the adoption of switching to a conservation practice beginning in the decision year. Thus, this damage function compares the private profitability of choosing the erosive, traditional, conventional practice over the conservation practice in the decision year. The damage function is expressed as follows:

$$(1) \quad Ft=Fe-Fc$$

where Ft is the value of the damage function in year t, that is, the private economic value of choosing the erosive practice over the conservation practice in the decision year t; Fc is the private profitability of choosing the conservation practice in decision year t; and Fe is the private profitability of choosing the conventional erosive practice currently and delaying conservation adoption another year. The farmer's cropping choice affects immediate profit in the decision year as well as his long term profit, as soil productivity is reduced differentially by distinct cropping practices.

The private profitability of using the erosive practice in the decision year, Fe, is equal to the present value of the net revenue stream from continuing traditional conventional tillage again in the decision year, followed by conservation tillage at reduced solum depth in each succeeding year of the time horizon. Thus, Fe is expressed as follows:

$$(2) \quad Fe = \big(P.Ye[T_1,X(t,Ee,Ff)]-Ce\big) + \frac{\big(P.Yc[Tc_1X(t+_1Ec_1Ff)] - [Ce+Cc]\big)}{1 + r}$$

$$+ \sum_{i=2}^{I-1} \frac{\big(P.Yc[Tc,X(t+i,Ec,Ff)] - [Ce+Cm]\big)}{(1 + r)^{i}}$$

where P is price of crop per unit produced; Ye, crop yield with traditional erosive practice as a non linear function of technological level, T_1, and solum depth, X, at the beginning of the decision year, t. Solum depth, X, is assumed to be a linear function of t (starting in a reference year with an initial solum depth Xo), a given erosion rate under specific cropping system and other erosion factors, Ee, and an assumed rate of soil formation, Ff; Ce is variable cost of production with erosive practice at a technological level T_1; Cc is the cost of setting up the conservation practice for the first time in the year of adoption; Cm is the cost of maintaining the conservation practice in the subsequent years after its adoption; Yc is the projected crop yield with conservation practice as a function of technological level, T_1 and solum depth, X which is assumed a linear function of an erosion rate with the adopted conservation practice, Ec and a rate of soil formation Ff; r is the real rate of discount; and i is the year number in the time horizon.

The private profitability of using the conservation practice in the decision year, Fc, is equal to the present value of the net revenue stream from adopting conservation practice in the decision year. Fc is expressed as follows:

$$(3)\quad Fc = \Big(P.Yc[Tc,X(t,Ec,Ff)] - [Ce+Cc]\Big) +$$

$$\sum_{i=1}^{I-1} \frac{\Big(P.Yc[Tc,X(t+i,Ec,Ff)] - [Ce\ \ Cm]\Big)}{(1+r)^{i}}$$

The difference in the bracket term of Fe and Fc equations is that solum is deeper by the erosion avoided with conservation tillage in the decision year. If in equation (1) Ft is greater than 0, the farmer will gain from employing the erosive practice in year t and therefore there will be an economic incentive for conserving the soil.

The damage function exhibits several properties which conform to empirical observations of farmer behavior. The damage function, Ft, would assume a higher positive value, encouraging the farmer to mine the soil, as (1) the yield of the erosive practice increases relative to the yield of the conservation practice; (2) the cost of the conservation practice increases relative to the cost of erosive practice; (3) the price of the crop increases; (4) the rate of discount increases; and (5) yield declines from soil erosion decrease.

Because the yield damage with further soil loss increases at shallower topsoil depths (Pawson et al., 1961), the economic incentive for continued use of erosive practices would decrease as erosion proceeds. If in a subsequent decision year Ft becomes negative, it would be economic for the farmer to adopt conservation practices at that time. Since short cycle cropping decisions are made annually, the damage function allows simulation by treating the adoption year as a variable and conducting incremental analysis of the impact of further erosion each year. This dynamic treatment of adoption year in the damage function simulation conforms more closely with the reality of the adoption decision process. Farmers may become concerned with the cumulative effect of erosion at some intermediate point in a time horizon.

The above depicted damage function was applied to the cropping and soil conditions of Las Cuevas watershed. As mentioned earlier, the major short-cycle crop in the region is red beans and it is often grown in rotation with rice in the moderate erosion potential area, or in multiple cropping with corn and pigeon peas in the higher erosion risk areas. The analysis assumed that farmers of Las Cuevas were aware of the erosion problem and their decisions about whether or not to adopt soil conservation practices would be made on the basis of comparing the immediate and long term profitability of cropping beans with and without soil conservation practices. Quantity and quality yield data availability related to soil depth restricted the analysis to the case of red beans, the most widely cultivated crop in the area.

The farm and farmers' survey provided the data to derive functions relating bean yield, Y, and solum depth, X, for the two main technological levels identified in the watershed: irrigated beans with fertilizer and plowed land, and rainfed beans usually cultivated by multiple cropping, with no fertilizer and on unplowed land. Irrigated beans were found almost exclusively in the area of moderate erosion risk, and rainfed beans were in the areas of greater erosion hazard. The erosion damage function was applied to these two levels of technology under shallow and deeper topsoils. The basic simulation was carried out employing the following data and assumptions:

(1) An 8 percent real private rate of discount is used to calculate present values. This was the current rate of discount in the region at the time of the survey.

(2) Farmers' decisions about soil conservation adoption are made annually by weighing immediate plus future profits of cropping with

traditional erosive practices, as compared to the use of conservation practices.

(3) Field observations and the subsample of farmers carrying out conservation practices showed that stone barriers and bench terraces were the conservation practices most recommended by the LWD in the region. Stone barriers are recommended for moderate erosion risk areas, and bench terraces for higher erosion risk fields. Consequently, simulation involved two cases: first, traditional cropping practice of beans using fertilizer and plowed land was compared to an identical situation but one adopting stone barriers as a soil conservation practice; second, traditional cropping practice of beans without fertilizer and unplowed land was compared to the adoption of bench terraces, under the same technological level.

(4) Average costs per tarea of the conservation practices were provided by the LWD in the region.

(5) Average rates of erosion in the case of moderate erosion risk are assumed to be 0.78 cms. (Santana, 1981) without conservation practices, and 0.29 cm with stone barriers. In the case of high erosion risk, erosion rates without conservation practice were assumed to be 4.39 cms. (Santana, 1981) and 0.79 cm with bench terraces (estimated using typical P values in the USLE).

(6) Annual soil formation was assumed to be 0.067 cm in the case of moderate erosion risk and 0.033 cm under high erosion risk. These limits are within the range of soil formation rates estimated by some researchers (Lombardi and Bertoni, 1975; Wischmeier and Smith, 1978). Differences in the assumed figures indicate more favorable soil

formation conditions in the areas of moderate erosion risk than those in areas of higher erosion risk.

(7) It was assumed that crop prices, production and conservation costs are constant in the planning horizon. The assumed prices and costs were the average of those found in the farmers' survey.

Sensitivity analysis was conducted to see how changes in model parameters would affect simulation outcomes. Different initial solum depths, planning horizons, decision years, discount rates, conservation costs, and crop prices were used to evaluate farmers' behavior under a variety of circumstances.

CHAPTER IV
ANALYTICAL RESULTS

Factors Affecting Soil Erosion Potential in Las Cuevas

Soil erosion potential is referred to as the maximum amount of soil loss that may be produced under no soil cover. Factors determining this erosion potential are evaluated on a site-by-site basis and are people-independent in a broad sense. This section demonstrates the behavior of rainfall erosivity, soil erodibility and slope gradient within the watershed, as inferred from the statistical and spatial analyses. Furthermore, an identification of erosion risk units is proposed to define intermediate planning subregions with specific soil conservation needs.

Rainfall and Erosivity Characteristics

Relatively long records of precipitation were available only for Padre de Las Casas, located in the western portion of the watershed. Total annual average precipitation is 978 mm and is distributed irregularly during the year, as indicated in Figure 4.1. The pattern of rainfall distribution is bimodal, with a major dry period from November through March, and a short decrease of rainfall in July. As a consequence of this pattern, a critical period of greater erosion propensity occurs from the end of March until the middle of May, as depicted in Figure 4.1. In this period, the percentage of ground cover is low, natural vegetation is very scarce due to the previous

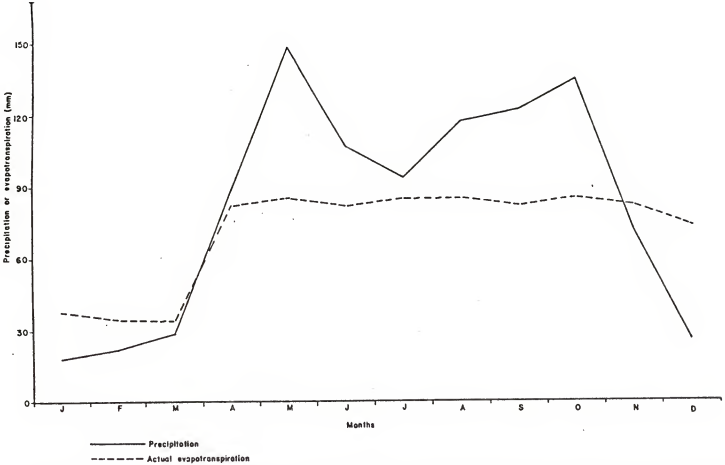

Figure 4.1. Annual rainfall and estimated evapotranspiration distribution, Padre de Las Casas.

dry period, and agricultural land is being cleared and planted. These two conditions favor soil erosion, particularly if intensive storms occur.

Erosivity values for the watershed, estimated by interpolation from the national erosivity map (SEA-IICA, 1982), range from 300 to 1000 tons/ha/year, but more than 50% of the watershed has erosivity values around 1000 tons/ha/year. With these values, rainfall aggressiveness in Las Cuevas is one of the highest in southwestern Dominican Republic. The erosive power of the rainfall in the region is considerably higher than the usual values in temperate zones, confirming again what has been widely known about the higher erosivity of rains in tropical and subtropical environments. The great amount of kinetic energy of rains is by itself a natural threat to soil conservation in the region. This is even more serious if one takes into account the fact that greater erosivity generally coincides with the steep slopes commonly found in the region. Figure 4.2 shows the estimated variation of erosivity in the watershed. Lowest values are in the west, increasing toward the east-central area.

In addition to the erosion-related consequences derived from the annual regime of precipitation and erosivity, the region suffers sporadically the devastating effects of hurricanes which move tremendous amounts of soil along the cyclical torrents formed by the concentration of excessive runoff. The potential erosion effect of the hurricanes, endemic to the Caribbean, unfortunately is not included in this assessment of erosion potential, but it should deserve special attention given the magnitude of damage to the topsoil.

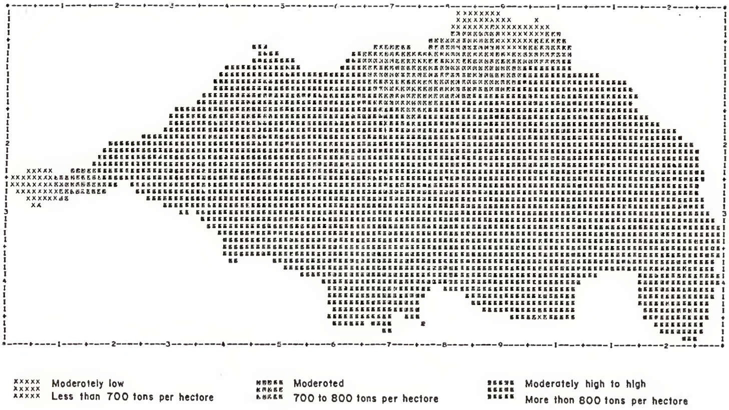
Moderotely low
Less than 700 tons per hectore
Moderoted
700 to 800 tons per hectore
Moderately high to high
More thon 800 tons per hectore

Figure 4.2. Spatial distribution of erosivity.

Topographic Characteristics

The direct relationship between slope gradient and length, and soil loss by rainfall is well documented in the literature. Any evaluation of erosion risk must consider the absolute value and relative variation of these topographic factors. Average slope gradient for sampled sites was 26.4%, but values range from 0 to more than 100%. More than 60.0% of the watershed has slopes greater than 20.0%, which indicates a very high risk of soil loss if soil surface is unprotected. Figure 4.3 shows the spatial variation of slope in Las Cuevas. Slope mapping classes are consistent with the categories normally applied by the LWD.

Field observations show high slope variability in the watershed, which is confirmed statistically by its coefficient of variation, with a value of 70%. As it should be expected from the geomorphological bases of form and process relationships, slope in the region is strongly associated with the dominant macro-geomorphic process at the watershed level. Denudation is dominant in most of the watershed and high slope gradients are present almost everywhere. Deposition is dominant only in the western lowland portion of the basin, and in some isolated floodplain tracts. Las Cuevas watershed is not stable geomorphologically and human activity is subject to natural hazards derived from these inherent characteristics.

Soil Erodibility Characteristics

Previous research has demonstrated that soil susceptibility to erosion is influenced by several soil properties, from which organic

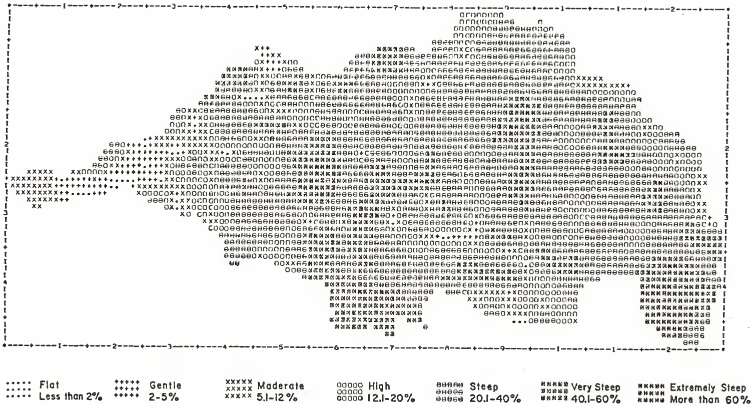

Figure 4.3. Spatial distribution of slope gradient.

matter and soil separate proportions appear as some of the most important. Erodibility was estimated for each sample site using the first approximation of Wischmeier diagram (Wischmeier, 1975), based on soil separate proportions and organic matter content. Although in absolute terms, these values may not be accurate, their relative variation within the watershed are useful arguments to the objectives of this study.

The inverse relationship between organic matter content and soil erodibility is very well documented in the literature. Average organic matter content was about 4.5%. This value is moderately high although its variability also is moderately high as expressed by 48.0% as its coefficient of variation. Organic matter ranges from 0.2% up to more than 12.0%, but about 60.0% of sample sites showed organic matter varying from 3.0 to 7.0%.

A significant positive but moderate correlation (0.355 at 0.99 confidence level) was found between organic matter content and altitude. This relationship is not surprising since altitude in subtropical and tropical areas determines mean annual temperature (Holdridge, 1964) and this in turn affects rates of organic decomposition. Organic matter in the soil increases as temperature decreases (Harradine and Jenny, 1958; Fridland, 1959; Wittaker et al., 1968; Holdridge, 1964; Duchaufour, 1982). Thus, in cool climates the forces of decomposition are less active than in warm climates and organic matter content is usually higher.

According to the results, if only organic matter is taken into account, it should be expected that soils at higher elevations in the watershed are less erodible than those of the lowlands. If this is not so, human intervention and very local conditions may be the more likely factors. Figure 4.4 indicates the approximate variation of organic matter content in the topsoil horizon throughout the watershed.

The second factor considered in the evaluation of soil erodibility in Las Cuevas was silt content in the topsoil horizon. Literature has pointed out the influence of this soil separate in determining the susceptibility of a soil to be eroded. In general, the greater the proportion of silt, the greater the erodibility of a soil (Richter and Negendank, 1977). Silt content in Las Cuevas ranged from 8 to about 50%, but 40% of the sample sites had more than 30% of silt which may be classified as moderately high to high silt content.

Figure 4.5 illustrates the estimated spatial distribution of silt content in the watershed. Silt variability does not seem as great as does organic matter, the value of the coefficient of variation being only 28%. This suggests that relative variations of soil erodibility within the watershed should be more influenced by organic matter than by silt proportion.

An index of the overall soil erodibility at each site was applied using the first approximation values in the erodibility nomograph (Appendix 1) of Wischmeier et al. (1971). In the absence of data for very fine sand fraction, as is the case in most standard soil laboratory analyses, only percentage of silt was used in the left entry of the diagram. This procedure resulted in an underestimation of absolute soil erodibility at each site, but its relative variation

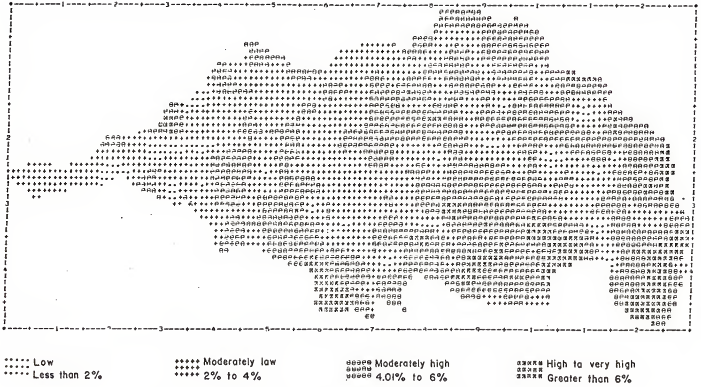

Figure 4.4. Spatial distribution of organic matter.

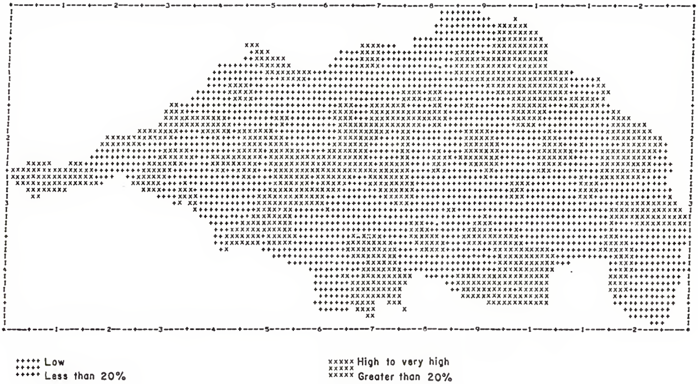

Figure 4.5. Spatial distribution of silt.

within the watershed was maintained. Figure 4.6 depicts the estimated distribution of soil erodibility determined by the influence of organic matter and soil separates in the superficial horizon of the watershed. Groups of erodibility values (K) were defined according to standard classes (Wischmeier, 1975).

The K values represent soil losses per unit of rainfall erosivity. Accounting for the underestimation mentioned above, these values are still relatively low, which may be due to the relatively high content of organic matter and clay particles in the topsoil horizon within the watershed. This low erodibility of soil might attenuate to some extent the great erosive potential effect of topographic and rainfall factors in the region. However, actual erosion rates depend overwhelmingly on the conditions of land use and land cover. This influence will be analyzed later.

Overall Erosion Potential

Using the Arnoldus approach (1977), an index of erosion potential was estimated for each soil sampled site. This index, as was described earlier, is really a partial application of the USLE to predict annual soil erosion potential for specific sites. Results shows that erosion potential varies greatly within the watershed, the value of the coefficient of variation was 123%. Erosion potential rates range from 6 to 18,949 ton per ha. (0.375 to 1184.31 ton per tarea). More than 50% of sampled sites had erosion potential greater than 1000 ton per ha.

Figure 4.7 shows the estimated distribution of erosion potential in Las Cuevas. The three categories were defined by the optimal rule

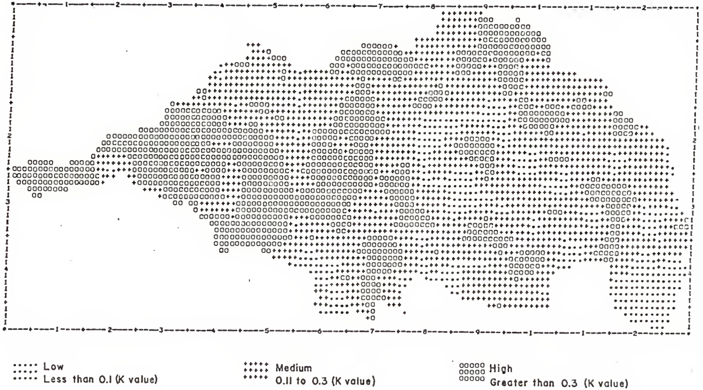

Figure 4.6. Spatial distribution of erodibility.

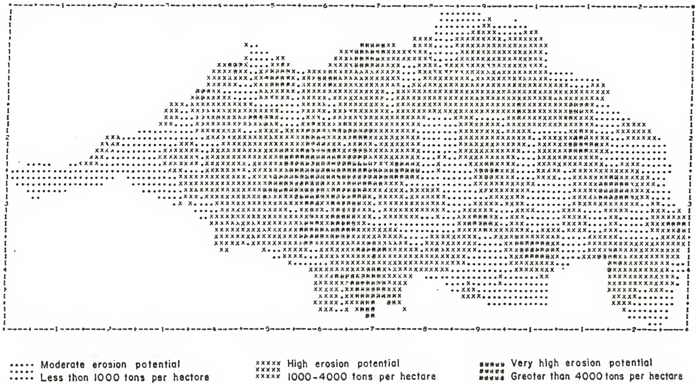
..... Moderate erosion potential
..... Less than 1000 tons per hectare
xxxxx High erosion potential
xxxxx 1000-4000 tons per hectare
##### Very high erosion potential
##### Greater than 4000 tons per hectare

Figure 4.7. Spatial distribution of erosion potential.

for stratification (Scheaffer et al., 1979). About 18% of the watershed was categorized as having low to moderate erosion risk; 50% with high, and the remaining with very high. These data show clearly the potential risk faced if no sound land use and land management is implemented in the region.

Actual Land Cover and Cropping Systems in the Watershed

In rigorous planning, and following the usual recommendations coming from developed countries, most of the Las Cuevas region should be maintained under natural forest and devoted to watershed protection. Actually, this is not the case. Since the end of nineteenth century, this watershed was inhabited increasingly by peasants displaced from other areas as a result of land concentration and population growth in the lowlands and adjacent highland ranges. These peasants came mainly from the area of San Juan de La Maguana, Constanza and San Jose de Ocoa.

By the second quarter of the twentieth century, as the watershed continued to be populated, permanent settlements had been established gradually along the main stream and its tributaries. Food was one of the major needs but the natural forest was an obstacle to performing agricultural activities. The task was to clear the forest and to plant food crops and some coffee trees. During this period, a sawmill was built at Padre de Las Casas and later another one was established at Las Lagunas; both accelerated the process of deforestation. In less than four decades the watershed was more than 80% denuded of trees and converted to marginal agriculture. Environmental considerations were absent to impede the use of this land for agricultural purposes.

Initially the best land was devoted only to cropping but later all types of land were gradually placed under continuous or shifting cultivation. The known cycle of slash-burn-crop-fallow was imposed instead of conserving the primary ecosystems. However, the kind of land uses and cropping systems set up in the watershed were not the same throughout the region nor did they result in homogeneous economic performance, as will be analyzed in the next sections.

The different land covers and cropping systems found in the sample of farms were grouped in eleven classes as shown in Table 4.1. These classes are referred to here as land uses and they reflect mainly differences in the proportion of ground cover and nature of management practices in farm plots throughout the year. The specific annual cropping calendar for various crops in the region is depicted in Figure 4.8.

Some farm plots with bare soil and/or rocky surface were found. Solum under these conditions was either absent or very shallow; stone pavement was usually present. According to the farmers, these fields were cultivated in the recent past, but they became useless due to the catastrophic effects of hurricanes. Most of these fields were located near tributaries of the Las Cuevas river.

Rotation of irrigated short cycle crops such as beans, rice and peanuts were found mainly on the floodplain close to Padre de Las Casas, in some isolated terraces along the Las Cuevas river or its tributaries, and in the reclaimed swamp area of Sabana de San Juan, to the southeast, where the production of vegetable crops currently is important. Farm fields under this land use usually have low

Table 4.1. Percent of land cover and cropping systems in Las Cuevas.[1]

Land use class	Percentage of area
Bare soil or rocky surface	0.08
Irrigated rotation of short cycle crops	4.18
Rainfed rotation of short cycle crops	3.14
Rainfed annual crops, mainly cassava	1.22
Rainfed multiple cropping of annual and short cycle crops	13.84
Subtropical dry forest	11.25
Rainfed permanent crops, excluding coffee	1.81
Fallow of pasture, mainly "yaragua"	34.56
Rainfed permanent pasture	8.92
Coffee with shade trees	10.91
Open pine and/or moist forest	10.09

[1] Percent with respect to total sampled area.

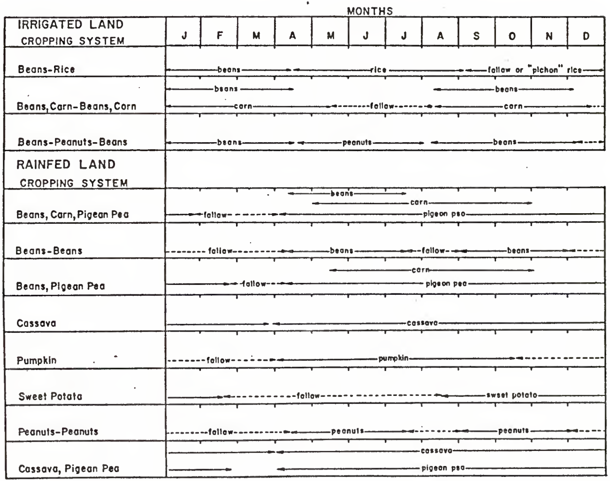

Figure 4.8. Calendar of major cropping systems in the watershed.

slope gradients and are cultivated continuously every year with two or more crops, one after the other. Most of these fields are fertilized and plowed either with animal traction or tractor. Weeding is done by hand with machetes.

When irrigated beans-rice rotation is practiced, land preparation takes place at the end of December; beans are planted in January and harvested at the beginning of April. Land preparation for rice transplanting starts almost immediately and includes land flooding, leveling and building of small dikes. Rice harvesting occurs in August-September, after which the land is often left under fallow or for rice sprouting.

As would be expected, irrigated cropping, in the moderate erosion risk area produces the highest average annual net return per tarea in the region, about D.R.$ 138.00 (Table 4.2). Land use normally is practiced in plots with very low slopes and intensive activity on the soil is not reflected in substantial impact on soil erosion. However, these farm fields usually are exposed to flooding, sediment deposition, and direct stream erosion. According to farmers, some of these fields have an erratic and catastrophic history; they have moved from one side of the river to the other or along the stream; these shiftings have been accompanied simultaneously by destruction of topsoil horizons or deposition of sediments, pebbles and stones.

The author observed that the risk of erosion is not absent in some of these fields; farmers very often overfill irrigation channels until hydraulic energy reaches dangerous limits carrying away considerable amounts of soil. Clearly, better irrigation practices are needed to improve the use of the water and avoid erosion risk.

Table 4.2. Average annual net return per tarea for various cropping systems in Las Cuevas.[1]

Land Cover and/or Cropping System	Erosion Potential Units Moderate	High	Very High
Bare soil or rocky surface	0.00	0.00	--
Irrigated rotation of short cycle crops	138.00	40.14	36.49
Rainfed rotation of short cycle crops	10.52	54.34	8.43
Rainfed annual crops, mainly cassava	10.80	12.60	12.04
Rainfed multiple cropping of annual and short cycle crops	15.85	12.97	12.84
Subtropical Dry Forest	0.00	0.00	0.00
Rainfed Permanent Crops, excluding coffee	6.78	8.93	4.01
Fallow of Pasture, mainly "yaragua"	0.00	0.00	0.00
Permanent pasture, mainly "yaragua"	--	--	--
Shade coffee	12.06	12.41	10.07
Open Pine and or Moist Forest	0.00	0.00	0.00

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[1] In D.R. $; D.R. $ 2.80 per $ U.S. dollar in 1984.

Rainfed rotation of short cycle crops was found mainly in old high terraces such as at La Meseta, La Guama, and on other areas of rolling topography. Typical rotations include beans-peanuts, beans-corn, and peanuts-peanuts. Land may be prepared with animal traction, but sometimes the only preparation consists of clearing the fields from weeds and bushes using machetes and fire, right before the start of the rainy seasons. Since this form of land management leaves the soil completely bare, substantial amounts of soil particles are lost during the first rains that normally come between the planting and the germination periods of the new crop. In addition, unplowed soil has less infiltration rates and, therefore, runoff tends to increase augmenting the danger of rill and gully erosion by water concentration. On the other side, particles in plowed soils tend to be less aggregated and relatively easy to separate and transport by rain drops and superficial runoff. Thus, under saturated conditions, plowed soils are likely to have more erosion than unplowed ones.

Several reasons might explain the lack of plowing for cropping. Other than topographic constraints, these reasons include cost savings and scarcity of animal traction in the region. Few words are needed to explain the difficulties of plowing on slopes greater than 15.0%. However, that is not the main factor to explain the absence of plowing. Instead, the lack of capital availability and the relatively high cost of land preparation pushes farmers to use a cost saving practice, which is not necessarily a cost effective one.

Fields with solely rainfed annual crops are found sparsely throughout the watershed. Cassava and pigeon peas were the two main crops in this land use class. Although isolated cassava plants are found normally on every farm, plots greater than 1 tarea are relatively few. Cassava production is devoted exclusively to home consumption; prices at farms are very low. Land preparation normally consists of clearing the fields by cutting and burning the "Yaragua" or "Yerba de Guinea", and planting cassava stems. Cassava often is cultivated on steep to very steep slopes. Fertilizer is not used. Clearing of plots and planting usually are carried out in March or August. The crop period may last longer than one year, depending on the cassava variety. As in the case of all other short and annual crops, the danger of erosion is greater in the period between land clearing and crop sprouting, not only because the soil is practically bare, but because the rainy season starts and storms of high intensity may occur.

Although cassava plants maintain a certain percentage of land cover for almost one year, soil protection is not guaranteed, particularly after weeding, since cassava leaves are not compact and more direct drops can splash onto the soil than is the case of, for example, beans, in which soil is relatively well covered during the second part of the crop cycle.

Rainfed multiple cropping of annual and short cycle crops is the more extensive cropping system found throughout the watershed, on rolling, steep and very steep lands. The typical multiple association includes pigeon peas, red beans and corn. Since some activities, such as land preparation and first weeding, are common for all the crops in one plot, this is a cost-savings system. These plots have at least some crop cover during most of the year and can provide more than two harvests of food crops at different times annually, i.e., beans in July, corn in September, and pigeon peas in December.

Pigeon peas appears to be the lowest risk since it is relatively resistant to the likely dryer conditions of rainfed agriculture. In addition to the first harvest, pigeon peas normally can provide two small harvests by allowing reflorescence in the following three months. Farmers in the region like this characteristic, particularly because the harvesting of pigeon peas coincides with dryer months, when no other fresh grains are available. Normally, part of pigeon peas production goes to the market and the other is left for home consumption.

Most multiple cropping plots are not plowed nor are they fertilized, therefore, productivity is low and runoff tends to increase. A typical area of multiple cropping is found at Las Lagunas, but this system is practiced on most farms. Theoretically, multiple cropping should be more soil protective than rotation of individual crops due to greater and more permanent ground cover throughout the year; however, if weeding time coincides with erosive storms, actual soil losses also may be great (Blomer, 1983).

Rainfed permanent crops, excluding coffee, are found in relatively small fields. Plantain is the most important crop in this category. It is planted usually in those farm sites with more water retention and/or greater soil depth, normally in lower slope farm sites. This is exactly the reverse of the usual recommendations of conservation scientists who suggest planting permanent crops on steep slopes and short cycle crops on lower slopes. Plantain may be considered as a soil protector crop due to several properties: its productive life may last for more than three years; its leaves are long and wide, which guarantee more soil protection from rainfall drop impact; and, mulching produced by dropped dry leaves normally results in a ground cushion effect against rainfall impact and a barrier against runoff speed.

Plantain production in the region is oriented almost exclusively to home consumption. Prices in the region are very low and peasants' cultural tradition teaches not to sell "viveres" such as plantain or cassava, but exchange them within the community. Thus, plantain is not a source of cash and, therefore, there is no real incentive to plant it more widely other than to supply family food. Because of this fact, plantain is found on most farms but in plots of less than 1 tarea.

Coffee associated with "guama" and/or plantain was found in about 10% of the sampled area, mainly above 800 meters elevation. As is well known (Suarez de Castro, 1982; Rocheleau, 1983), the effect of shaded coffee on soil losses is similar to that of natural forest. The presence of abundant mulching and ground cover makes this land use a good soil protector crop. Typical areas of coffee farms in the watershed are Monte Bonito, Arroyo La Savila, Arroyo Corozo, Lagunitas and Miguel Martin. However, most coffee trees are more than 30 years old and average yields are very low. Coffee plots vary from low to very steep slopes.

Although some efforts have been made in the region to implement a program to renew coffee plantations and introduce more productive varieties, the prospect is very limited by the nature of the program itself, by negative past experiences of farmers as debtors of official loans, by the farmers' uncertainty regarding the success of the program, and by the fear about the devastating effects of possible future hurricanes.

Although coffee prices relative to other crops could provide a good incentive to plant this soil-protective crop, the cost of establishing a new plantation is relatively high given the scarcity of capital in the region, the length of return period, the rainfed dependence, and the threat of future hurricanes.

Land use class referred to as fallow is actually part of the total land devoted to short cycle and annual crops. Fallow land is cultivated for two or more years and then abandoned as fallow for two or more years. This local technique of land rotation, similar to that of shifting cultivation in many parts of the world, is used as a strategy to recover temporarily soil productivity, by leaving soil resting under the invasion of weeds, pastures and some shrubs. The more common of these pastures is "yaragua" (Minutis minutiflora), a grassy pasture that invades open plots very easily, but is hard to clear from them once the invasion has been completed. To convert this fallow land into cultivatable land, farmers clear the ground by cutting and burning the weeds a few weeks before planting. Thus, here again, the first rains of the season are generally present when these fields are completely bare. If these rains are of high intensity, only one storm may produce enough runoff to carry away considerable amounts of soil, as Suarez de Castro (1980) and Rocheleau (1983) have observed in field experiments carried out in Colombia and the Dominican Republic respectively.

Subtropical Dry Forest covers low hills and high terraces in the western part of the watershed. This open forest is composed mainly of thorny shrubs. Most of these shrubs have small sparse leaves and, therefore, many rainfall drops can splash the ground directly. Ground cover is scarce during most of the year, but in some cases cattle are pastured during the rainy seasons. Slopes usually are greater than 20%, gullies are very frequent (Table 4.3) and solum is often shallow. Fields under Dry Forest are relatively large and in the hands of very few owners. These fields do not have specific systematic use, except as sources of firewood. In the recent past some attempts were made to develop medium-scale goat projects with government support, but they failed due to technical mismanagement, according to persons closely related to those projects.

Relevance of Identified Erosion Risk Units

Geographers and planners have stressed the importance of designing homogeneous planning regions to facilitate the formulation of specific strategies and targets. This is important at the watershed level where a need exists to delineate subregions for planning and implementing rational development of natural resources.

Three spatial units with respect to erosion factors were identified in the section dedicated to evaluate overall erosion potential. These units are theoretically homogeneous in terms of soil conservation needs. However, soil conservation strategies must take

Table 4.3. Occurrence of gullies according to land cover or cropping system in the sampled farm plots.[1]

Land use or land cover class	Active Gullies	Stable Gullies	No Gullies
Rocky surface or bare soil	66.67	0.00	33.33
Irrigated rotation of short cycle crops	0.00	0.00	100.00
Rainfed rotation of short cycle crops	29.63	7.41	62.96
Rainfed annual crops, mainly cassava	9.09	9.09	81.82
Rainfed multiple cropping of annual and short cycle crop	16.06	8.76	75.18
Subtropical dry forest	100.00	0.00	0.00
Rainfed permanent crops, excluding coffee	6.67	3.33	6.67
Fallow of pasture	44.64	14.29	41.07
Permanent pasture	38.46	15.38	46.15
Coffee	11.36	4.55	84.09
Open pine and moist forest	16.67	50.00	33.33

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[1] Percentage of plots in each land use class.

into account also the profitability and current use of land resources. Land is divided into farms, and each farmer has his own way of making use of it. Farmers' decisions are influenced in some way by erosion causing factors found on the farm; this should be reflected in differences of actual land use and farmers' economic performance from one erosion risk area to another. Such units would be appropriate also as broader planning areas.

Consequently, tests were performed to compare the following selected farm field conditions among the three erosion risk areas: (1) average field slope gradient; (2) average field slope length; (3) solum depth; (4) average net revenue per tarea; (5) land use frequency; (6) presence of gullies; (7) presence of rills; and (8) presence of landslides. Duncan's Multiple Range Test, DMRT, (Duncan, 1956) was used to compare average conditions of variables in Table 4.4 among the three areas. Table 4.4 summarizes average conditions of farm fields and DMRT results.

Average slope gradient of farm plots is greater in higher potential erosion areas. Actual solum depth and average annual net revenue per tarea seem to decrease in the areas of higher erosion risk. This is not surprising since soil depth is the result of soil forming and soil eroding processes. Shallow soils may be associated with accelerated erosion. Solum depth figures in Table 4.4 suggest that accelerated erosion in the higher risk units may be the cause of such shallow soils. Erosion has been accelerated by the kinds of land use in the region.

Slope gradient of farm plots was found to be significantly different among the three areas. This partially validates the

Table 4.4. Average conditions of selected variables in the farm plots of the three erosion risk units.

Variable	Erosion risk areas Moderate	 High	 Very High
Slope gradient (%)	18.78 a*	32.39 b	32.61 c
Slope length (m)	127.25 a	149.88 b	147.34 b
Solum depth (cm)	63.74 a	48.72 b	43.81 b
Net Revenue per ta. ($)	45.59 a	14.13 b	9.29 b

*Comparative values within rows not marked by the same letter are significantly different at 0.05 level of probability according to Duncan's Multiple Range Test, DMRT (SAS Institute, 1979).

relevance of the subregionalization procedure, since slope gradient is perhaps the most deterministic factor of erosion risk. Test results also show that farm plots located in the two higher erosion risk units are not significantly different in terms of slope length, solum depth and average net revenue per tarea. Plots located in the moderate erosion risk area are significantly different from those in the others. According to these results, it may be advisable to group the two higher erosion risk areas into one for purposes of regional agricultural development planning.

A chi-square test (Agresti and Agresti, 1979) was performed to test for independence between the theoretically defined erosion risk areas and the actual presence of gullies, rills, landslides and specific land uses in farm plots. Table 4.5 suggests that the actual proportion of farm plots with active gullies increases in the higher erosion risk areas. The chi-square test shows that there is a significant association (at 0.10 confidence level) between the potential erosion risk and the actual presence of gullies. However, the degree of this association is relatively weak, as indicated by the value of chi-square, equal to 0.133.

The relative occurrence of active rills increases with higher erosion risk, as is depicted in Table 4.6. The chi-square test confirms this observation, indicating a significant association (at 0.99 confidence level) between the potential erosion risk and the actual occurrence of rills, but the degree of association is relatively weak, as evidenced by the value of phi-squared equal to 0.222.

Table 4.5. Occurrence of gullies in the sampled farm plots.[1]

Gully status	Erosion Risk Units					
	Moderate		High		Very high	
	No.	%	No.	%	No.	%
No gullies	83	80.6	156	70.3	72	66.1
Stable gullies	3	2.9	21	9.4	10	9.2
Active gullies	17	16.5	45	20.3	27	24.8
Subtotal	103	100.0	222	100.0	109	100.0

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[1] Figures indicate number and percentage of plots with respect to total plots in each erosion risk unit.

Table 4.6. Occurence of rills in the sampled farm plots.[1]

Rill Status	Erosion Risk Units Moderate No.	 %	 High No.	 %	 Very High No.	 %
No rills	88	85.4	155	69.8	65	59.6
Stable rills	0	0.0	17	7.7	7	6.4
Active rills	15	14.6	50	22.5	37	33.9
Subtotal	103	100.0	222	100.0	109	100.0

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[1] Figures indicate number and percentage of plots with respect to total plots in each erosion risk unit.

Although the occurrence of landslides apparently follows the same pattern, as indicated by Table 4.7, there was not enough evidence of significant association between erosion risk potential and the actual development of landslides in the farm fields. This may suggest that, in addition to the factors taken into account to evaluate erosion potential, there are other factors that may influence the occurrence of landslides in the region. These factors could include parent material and subsoil characteristics, as is inferred by the degree of landslide clustering observed during the field work. A closer examination of landslide factors deserves additional study.

A possible association between actual land cover or cropping system, and the theoretical erosion risk areas also was attempted. Table 4.8 shows percentages of farm plots under specific land cover or cropping system, with respect to total number of sampled farm plots in each erosion risk area. Most farm plots located in the area of moderate erosion risk are devoted to irrigated short cycle crops, or rainfed multiple cropping. The major proportion of farm plots in the higher erosion risk areas also are under rainfed multiple cropping. The proportion of plots under old shaded-coffee also increases in the areas of higher erosion risk. Otherwise, there is no suggestion of an overall pattern of association between actual land use and erosion risk areas, except for the case of irrigated agriculture, which is almost exclusively situated in the moderate erosion risk areas. Difficulties were found in using chi-square as a test of association since data on Table 4.8 were so sparse that the assumptions and requirements for a valid chi-square test were not fulfilled. Thus,

Table 4.7. Occurrence of landslides in the sampled farm plots.[1]

Landslides Status	Erosion Risk Units Moderate		High		Very High	
	No.	%	No.	%	No.	%
No landslides	88	85.4	183	82.4	84	77.1
Stable landslides	10	9.7	23	10.4	11	10.1
Active landslides	5	4.8	16	7.2	14	12.8
Subtotal	103	100.0	222	100.0	109	100.0

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[1] Figures indicate number and percentage of plots with respect to total number of plots in each erosion risk unit.

Table 4.8. Percent distribution of farm plots by land cover or cropping system in the erosion risk areas.[1]

Land Cover and/or Cropping System	Erosion Risk Unit Moderate	High	Very High
Bare soil or rocky surface	0.97	0.90	0.00
Irrigated rotation of short cycle crops	28.16	4.50	0.92
Rainfed rotation of short cycle crops	5.83	7.21	4.59
Rainfed annual crops, mainly cassava	5.83	5.41	3.67
Rainfed multiple rotation of annual and short cycle crops	28.16	30.63	36.70
Subtropical Dry Forest	2.91	3.15	1.83
Rainfed permanent crops, excluding coffee	5.83	5.86	10.09
Fallow of pasture, mainly "yaragua"	8.74	14.86	12.84
Permanent pasture, "yaragua" and "guinea"	2.91	2.25	4.59
Shade coffee	9.71	23.42	23.85
Open pine and/or moist forest	0.97	1.80	0.92

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[1] Percent with respect to total number of plots in each

land cover and cropping systems were grouped into four classes (Table 4.9) in order to reduce sparseness of data and, therefore, carry out a valid test.

Table 4.9 shows that in all three erosion risk areas, the higher proportion of farm plots is devoted to short-cycle and/or annual cropping, and the lowest proportion corresponds to dry or moist subtropical forest. This demonstrates that deforestation has occurred everywhere, regardless of erosion risk. Table 4.9 chi-square test indicated a significant association (at 0.01 confidence level) between land use classes and erosion risk areas. The degree of this association is weak as it is concluded from the phi-squared of 0.195. In fact, the ranking of importance of land use classes in this table is the same for the three erosion risk areas. What is somewhat different is the magnitude of the relative proportion of plots. The test reflects this feature, which is clearly depicted in Table 4.9 for the case of short-cycle and/or annual crops, and permanent crops. Table 4.9 also suggests that land use in the region actually is organized in such a way that the higher the erosion risk the lower the proportion of plots devoted to short-cycle and annual crops. This would appear as an environmentally rational decision by the farmers in the region. However, this conclusion is dismissed by the fact that close to 50% of the plots are cropped in areas that should be devoted to non agricultural use, according to more rigorous land management recommendations. Thus, the observed differences might be explained by the limitations that erosion factors themselves impose on the performance of agricultural activities in areas of higher erosion

Table 4.9. Distribution of farm plots by groups of land cover or cropping systems in the three erosion risk areas.[1]

Groups of Land Cover or Cropping System	Erosion Risk Units					
	Moderate		High		Very High	
	No.	%	No.	%	No.	%
Short cycle and/or annual crops	70	68.60	106	48.18	50	45.87
Dry or moist subtropical forest	4	3.92	11	5.00	3	2.75
Permanent crops	16	15.69	65	29.55	37	33.94
Fallow or permanent pasture	12	11.76	38	17.27	19	17.43
Subtotal	102	100.00	220	100.00	119	100.00

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[1] Percentage with respect to total number of plots in each erosion

risk rather than by a farmers' environmental awareness. If it is accepted that most plots labeled as fallow actually are subject to periodic burning and cropping, the cropped area increases in the three erosion risk units and the absence of environmentally rational decision making on the farmers' part is still more evident.

Farmers' Perception of Soil Erosion

Only 10% of the interviewed farmers referred explicitly to soil erosion as one of their three major problems. However, another 20% mentioned problems such as "tired plots", "lack of soil force" and "shallow soils", which could be related in some way to accelerated soil erosion. The rest, 70% of farmers, did not consider erosion-related problems at all. According to these results, three general groups of farmers seem to be identified: farmers who are aware of the agents, process and consequences of soil erosion; farmers who are aware of soil exhaustion but do not perceive the possible causes; and farmers who have little or no awareness of erosion processes or their consequences.

Most of the Las Cuevas farmers seem to view themselves as being subjected to whims of nature beyond their control. This attitude towards nature strongly illustrates the influence of culture and fits more closely within the category that typifies preindustrial societies and areas of pioneer settlement. Such views, coupled with limited technological resources, tend to generate resigned acceptance and fatalism. For a typical farmer of Las Cuevas, there is little or nothing which can be done if a storm damages his land by opening channels or gullies. He simply accepts the inevitable as beyond human control.

When farmers were asked to state in their own words (Appendix 3) their perception about the importance of soil erosion on their farms, 90% referred to this problem as having little or no importance at all. The remaining 10% gave moderate to high importance to the erosion problem. On the basis of these results, a discriminant function was estimated and tested.

After the correlation analysis (Table 4.10), four out of the eight variables in the original set were selected as the independent variables for the discriminant function. The discriminant analysis (Appendix 4) demonstrated that it is possible to ascertain the perception of farmers regarding the importance of soil erosion with relatively few variables related to the environmental characteristics of the farms and economic performance of the farmers. Perception of the importance of the soil erosion problem was stronger with low net revenue per unit of farm land, presence of active gullies, shallow soils, and steep slopes.

When the significant discriminant variables found in this study are compared with the factors other authors (Kasal, 1970; Earle et al., 1981) listed as influencing farmer participation in soil conservation programs, it is found that neither farmers' age nor farmers' education level, nor farm size contributed significantly to the discriminant function, despite the fact that these factors were mentioned as significant by those researchers. This discrepancy may be explained by the differences among the farm populations being

Table 4.10. Correlation of the classifying variable (which is whether or not the farmer concedes importance to the erosion problem in his/her farm) with the set of hypothesized variables believed to influence farmer perception.

Variable	Correlation with dependent variable
Farmer age	-0.059
Farmer education	0.057
Years of farm operation	-0.096
Farm net revenue per unit of land	-0.121*
Farm average solum depth	-0.136*
Presence of gullies in the farm	0.266*
Presence of rills in the farm	0.099
Average farm slope	0.138*

*Correlation is significant at 10% level.

studied. In fact, about 46% of sampled farmers do not have any formal education; they do not read or write. About 43% have five or less years of formal education; and only 10% of farmers have more than five years' education. Since environmental education is almost absent from school programs, having more or less years of formal education does not make any difference, in terms of the perception of environmental problems.

Age differences among farmers do not seem to influence significantly the perception of the erosion problem. There is no evidence to suggest that young farmers have different perceptions than older ones; young farmers simply follow parents' perceptions and beliefs. This fact may be the result of strong cultural traditions that typify most traditional societies (Gold, 1980). Most of the farmers in the region may belong to this category.

The estimated discriminant function emphasized the influence of farm features (such as presence of gullies) on farmers' perception of erosion importance. This suggests that farmers tend to perceive erosion as a problem only when it has reached critical stages, such as evidence of gullies and very shallow soils. They apparently are not aware of the gradual and cumulative effects of soil erosion before a critical situation is reached. This perception may push farmers to do something to conserve the soil only when it is too late. The greatest perception of erosion apparently occurs as a result of a crisis, similar to literature on extensive and pervasive natural hazards (Burton and Kates, 1964; Burton et al., 1968). This farmers' behavior is very dangerous for the purposes of protecting the soil and makes soil conservation programs more difficult to implement.

A measure of the efficiency of classification of the discriminant function was obtained by classifying the respondents who provided the data from which the function was derived. The better the agreement between the predicted classification and the known classification, the more efficient the function would be. From the original data there were 189 respondents who conceded little or no importance to soil erosion on their farms giving a prior probability of (189/210) or 0.90 for non-erosion perception (and 0.10 for erosion perception). These prior probabilities were used to obtain the discriminant function which predicted 174 non-erosion perceivers. Table 4.11 summarizes the results of the analysis showing 85% of all respondents as correctly classified. Appendix 4 shows the classification results for each farmer.

Profitability of Adopting Soil Conservation Practices

The profitability of adopting soil conservation measures was analyzed by applying the proposed damage function to simulate soil conservation decisions. Data quantity restricted the analysis to the case of red bean production in which two technological levels were identified: (1) the higher technological level, characterized by plowed land and use of some fertilizer with irrigation, is practiced in the areas of low to moderate erosion risk in which stone barriers usually are recommended by the LWD; (2) the lower technological level, characterized by unplowed land, no or very little use of fertilizer, and rainfed agriculture, is practiced in areas of higher erosion risk in which bench terraces often are recommended as conservation measures by the LWD.

Table 4.11. Predicted classification of soil erosion perception using the discriminant function and actual soil erosion perception according to interviews.

Soil erosion perception group	Actual number	Number predicted by function	Number correctly classified	Number incorrectly classified	Percent of correctly classified
Erosion perceivers	21	36	13	23	87.83
Non-erosion perceivers	189	174	166	8	61.90

Percentage of total correctly classified = [(13 + 166)/210]100 = 85%.

Two functions (Table 4.12), one for each technological level, relating bean yield, Y, and topsoil depth, X, were estimated, based on non-linear regression analysis of the 1983 crop yield and soil depth cross-section data from the survey of farms and farmers. These functions are only a first approximation as they come from a cross-section data set; experimental work and longer observation periods are needed to produce more exact relationships. The estimated functions are asymptotic and exhibit increasing yield decline with further soil loss at shallow topsoil depths, as it is shown in Figures 4.9 and 4.10. The yield decline rate is greater in the higher technological level, for a given soil depth; the yield of the higher technological level normally is greater than that of the lower one.

Analysis with the damage function model indicated that on some soils, traditional-conventional tillage appears more profitable than tillage with conservation measures from a short run perspective. However, it becomes unprofitable (comparatively) as the long run yield damage is considered. Tables 4.13 through 4.22 indicate how the value of the damage function, Ft, varies for different planning horizons and topsoil depth conditions. The damage value becomes increasingly negative as the planning horizon is longer indicating that the farmer will be more inclined to adopt soil conservation as the planning period increases. However, if the planning horizon is too long the total topsoil will be lost anyway and the profitability of soil conservation adoption will decrease, as it is illustrated in Tables 4.13 and 4.15 when 75 years planning is considered for shallow solum.

Sensitivity analysis results are self-explanatory and are shown in Tables 4.13 through 4.22.

Table 4.12. Estimated functions relating bean yield, Y, and topsoil depth, X, for the two major erosion and technologic conditions in Las Cuevas.

	Moderate erosion risk Moderate technology		High erosion risk Low technology	
General form	$Y=b0+b1(1-e^{-b2X})$		$Y=b0+b1(1-e^{-b2}X)$	
	Estimated coefficients	Asymptotic St. errors	Estimated coefficients	Asymptotic St. errors
	b0= 0.092238	0.118134	b0=0.283613	0.042293
	b1= 0.983178	0.109463	b1=0.473005	0.106857
	b2= 0.055769	0.015079	b2=0.021223	0.012351

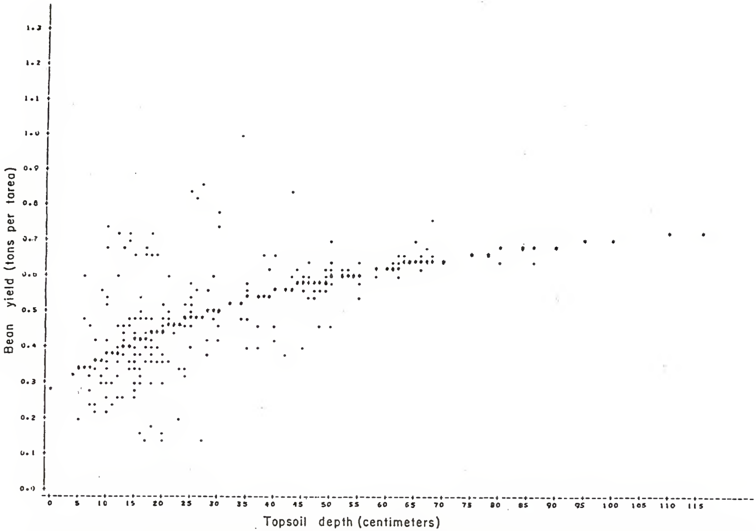


Figure 4.9. Estimated relationship between bean yield and topsoil depth under conditions of low technologic level and high erosion risk.

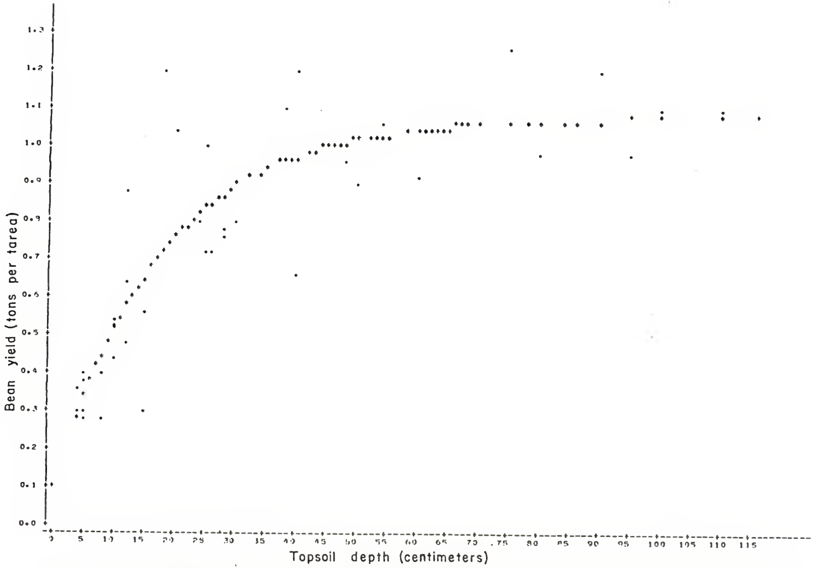


Figure 4.10. Estimation relationship between bean yield and topsoil depth under conditions of moderate technologic level and moderate erosion risk.

Table 4.13. Planning horizon sensitivity analysis, shallow solum,[1] low tecnologic level, high erosion risk, current year as decision year.

Planning horizon (years)	Fe[2] R.D.$	e-Topsoil[3] (cm)	Fc[4] R.D.$.	c-Topsoil[5] (cm)	Ft[6] (Fe-Fc) R.D.$
1	7.40	15.64	-0.09	19.24	7.49
10	10.99	8.07	16.27	12.43	-5.28
25	-0.38	0.00	12.04	1.07	-12.42
50	-9.98	0.00	3.57	0.00	-13.55
75	-10.24	0.00	2.32	0.00	-12.56

---

[1] Initial solum depth in the current year is 20 cm.

[2] Private profitability of choosing the conventional erosive practice and delaying conservation adoption another year.

[3] Solum depth at the end of the planning horizon if the conventional erosive practice is choosen in the decision year and conservation adoption is delayed another year.

[4] Private profitability of choosing the conservation practice in the decision year.

[5] Solum depth at the end of the planning horizon if the conservation practice is choosen in the decision year.

[6] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

Table 4.14. Planning horizon sensitivity analysis, deep solum[1], low technologic level, high erosion risk, current year as decision year.

Planning horizon (years)	Fe[2] R.D.$	e-Topsoil[3] (cm)	Fc[4] R.D.$	c-Topsoil[5] (cm)	Ft[6] (Fe-Fc) R.D.$
1	17.14	55.64	9.64	59.24	7.50
10	91.29	48.07	91.39	52.43	-0.10
25	137.59	36.71	140.87	41.07	-3.28
50	150.12	17.79	155.07	22.15	-4.95
75	150.31	0.00	155.63	3.22	-5.32

---

[1] Initial solum depth in the current year is 60 cm.

[2] Private profitability of choosing the conventional erosive practice and delaying conservation adoption another year.

[3] Solum depth at the end of the planning horizon if the conventional erosive practice is choosen in the decision year and conservation adoption is delayed another year.

[4] Private profitability of choosing the conservation practice in the decision year.

[5] Solum depth at the end of the planning horizon if the conservation practice is choosen in the decision year.

[6] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

Table 4.15. Planning horizon sensitivity analysis, shallow solum[1], moderate technologic level, moderate erosion risk, current year as decision year.

Planning horizon (years)	Fe[2] R.D.$	e-Topsoil[3] (cm)	Fc[4] R.D.$	c-Topsoil[5] (cm)	Ft[6] (Fe-Fc) R.D.$
1	18.36	19.27	15.36	19.78	3.00
10	112.59	17.04	114.27	17.78	-1.68
25	165.81	13.70	170.00	14.42	-4.19
50	177.49	8.12	199.40	8.85	-21.91
75	176.72	2.55	182.57	3.27	-5.85

---

[1] Initial solum depth in the currrent year is 20 cm.

[2] Private profitability of choosing the conventional erosive practice and delaying conservation adoption another year.

[3] Solum depth at the end of the planning horizon if the conventional erosive practice is choosen in the decision year and conservation adoption is delayed another year.

[4] Private profitability of choosing the conservation practice in the decision year.

[5] Solum depth at the end of the planning horizon if the conservation practice is choosen in the decision year.

[6] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

Table 4.16. Planning horizon sensitivity analysis, deep solum[1], moderate technologic level, moderate erosion risk, current year as decision year.

Planning horizon (years)	Fe[2] R.D.$	e-Topsoil[3] (cm)	Fc[4] R.D.$	c-Topsoil[5] (cm)	Ft[6] (Fe-Fc) R.D.$
1	34.18	59.28	31.18	59.78	3.00
10	235.91	57.05	234.66	57.78	1.25
25	373.82	53.70	372.85	54.42	0.97
50	427.05	48.12	426.21	48.85	0.84
75	434.55	42.55	433.74	43.27	0.81

---

[1] Initial solum depth in the current year is 60 cm.

[2] Private profitability of choosing the conventional erosive practice and delaying conservation adoption another year.

[3] Solum depth at the end of the planning horizon if the conventional erosive practice is chosen in the decision year and conservation adoption is delayed another year.

[4] Private profitability of choosing the conservation practice in the decision year.

[5] Solum depth at the end of the planning horizon if the conservation practice is chosen in the decision year.

[6] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

Table 4.17. Decision year sensitivity analysis, low technologic level, high erosion risk, 25 years of planning horizon, and 60 cm of topsoil in the current (present) year.

Decision year	Topsoil[1] (cm)	Fe[2] R.D.$	Fc[3] R.D.$	Ft[4] R.D.$	Adoption decision
Current year	60.00	137.59	140,87	-3.28	Immediate
Next year	55.64	127.56	131.52	-3.96	Immediate
5 years later	38.21	76.79	84.19	-7.40	Immediate
10 years later	16.43	-17.04	-5.39	-11.65	Immediate
25 years later	0.00	-58.83	-62.63	3.80	No adoption

---

[1] Solum depth at the begining of the decision year.

[2] Private profitability of choosing the conventional erosive practice in the decision year and delaying conservation adoption another year.

[3] Private profitability of adopting the conservation practice in the decision year.

[4] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

[5] Decision about whether or not to adopt soil conservation in the decision year.

Table 4.18. Decision year sensitivity analysis, moderate technologic level, moderate erosion risk, 25 years of planning horizon, and 60cm of topsoil in the current (present) year.

Decision year	Topsoil[1] (cm)	Fe[2] R.D.$	Fc[3] R.D.$	Ft[4] R.D.$	Adoption decision[5]
Current year	60.00	373.82	372.85	0.97	No adoption
Next year	59.28	372.74	371.81	0.93	No adoption
5 years later	56.38	368.17	367.34	0.83	No adoption
10 years later	52.77	361.34	360.65	0.69	No adoption
25 years later	41.92	330.17	330.32	-0.15	Immediate

---

[1] Solum depth at the begining of the decision year.

[2] Private profitability of choosing the conventional erosive practice in the decision year and delaying conservation adoption another year.

[3] Private profitability of adopting the conservation practice in the decision year.

[4] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

[5] Decision about whether or not to adopt soil conservation in the decision year.

Table 4.19. Rate of discount sensitivity analysis, low technologic level, high erosion risk, 25 years of planning horizon, and current year as the decision year.

	Shallow solum (20 cm)			Deep solum (60 cm)		
Rate of Discount	Fe[1] R.D.$	Fc[2] R.D.$	Ft[3] R.D.$	Fe[1] R.D.$	Fc[2] R.D.$	Ft[3] R.D.$
0.02	-20.51	5.76	-26.27	228.83	238.53	-9.70
0.04	-11.02	9.23	-20.25	189.19	196.06	-6.87
0.06	-4.67	11.11	-15.78	159.76	164.57	-4.81
0.08	-0.38	12.04	-12.42	137.59	140.87	-3.28
0.15	6.30	11.92	-5.62	91.55	91.69	-0.14

---

[1] Private profitability of choosing the conventional erosive practice in the decision year and delaying conservation adoption another year.

[2] Private profitability of adopting the conservation practice in the decision year.

[3] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

Table 4.20. Rate of discount sensitivity analysis, moderate technologic level, moderate erosion risk, 25 years of planning horizon, and current year as the decision year.

Rate Discount	Shallow solum (20 cm) Fe[1] D.R.$	Fc[2] D.R.$	Ft[3] D.R.$	Deep solum (60 cm) Fe[1] D.R.$	Fc[2] D.R.$	Ft[3] D.R.$
0.02	271.51	280.97	-9.46	643.87	643.51	0.36
0.04	225.79	233.02	-7.23	525.84	525.17	0.67
0.06	191.68	197.21	-5.53	438.94	438.12	0.82
0.08	165.81	170.00	-4.19	373.82	372.85	0.97
0.15	111.57	113.01	-1.44	241.60	240.28	1.32

---

[1] Private profitability of choosing the conventional erosive practice in the decision year and delaying conservation adoption another year.

[2] Private profitability of adopting the conservation practice in the decision year.

[3] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

Table 4.21. Conservation cost sensitivity analysis, low technologic level, high erosion risk, 25 years of planning horizon, and current year as the decision year.

Conservation	Shallow solum (20 cm)			Deep solum (60 cm)		
cost savings D.R.$	Fe[1] D.R.$	Fc[2] D.R.$	Ft[3] D.R.$	Fe[1] D.R.$	Fc[2] D.R.$	Ft[3] D.R.$
7.50	6.58	19.52	-12.94	144.48	148.26	-3.78
6.50	5.64	18.52	-12.88	143.54	147.27	-3.73
3.50	2.85	15.52	-12.67	140.75	144.26	-3.51
1.50	1.01	13.53	-12.52	138.89	142.25	-3.36
0.00	-0.38	12.04	-12.42	137.59	140.87	-3.28

---

[1] Private profitability of choosing the conventional erosive practice in the decision year and delaying conservation adoption another year.

[2] Private profitability of adopting the conservation practice in the decision year.

[3] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

Table 4.22. Conservation cost sensitivity analysis, moderate technologic level, moderate erosion risk, 25 years of planning horizon, and current year as the decision year.

Conservation cost savings D.R.$	Shallow solum (20 cm) Fe[1] D.R.$	Fc[2] D.R.$	Ft[3] D.R.$	Deep solum (60 cm) Fe[1] D.R.$	Fc[2] D.R.$	Ft[3] D.R.$
3.00	168.48	173.01	-4.53	376.55	375.75	0.80
2.50	168.01	172.50	-4.49	376.08	375.23	0.85
2.00	167.55	172.00	-4.45	375.61	374.72	0.89
1.50	167.08	171.50	-4.42	375.20	374.28	0.92
0.50	166.16	170.51	-4.35	374.24	373.28	0.96
0.00	165.81	170.00	-4.19	373.82	372.85	0.97

---

[1] Private profitability of choosing the conventional erosive practice in the decision year and delaying conservation adoption another year.

[2] Private profitability of adopting the conservation practice in the decision year.

[3] Private economic value of choosing the erosive practice over the conservation practice in the decision year. This is the value of the damage function.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

This study examined key problems facing the planning of soil conservation programs in the Las Cuevas watershed, Dominican Republic. The central factors investigated were: land factors related to erosion risk; cropping systems and land cover as related to soil losses; farmers' perception of erosion; farmers economic performance and its relationship to the erosive ranking of existing farming systems; and farmers' profitability of adopting conservation practices.

Two sets of data provided the basis for this study: a soil survey of more than four hundred stratified randomly sampled sites throughout the watershed and a regional stratified random sample of farmers in the region. Computer mapping, descriptive statistics as well as specific statistical and analytical procedures were used for processing and analyzing the information to achieve the specific objectives of this study. Chi-square and Duncan tests were carried out to demonstrate the relevance of the proposed intermediate planning units for soil conservation and agricultural development; discriminant analysis was used to test the influence of farmers' personal socioeconomic attributes and farm conditions on farmers' perception of the importance of the soil erosion problem on their farms; an erosion damage function was applied to measure on-site damage from agricultural soil loss and to evaluate private profitability of adopting conservation practices.

Las Cuevas is one of the most backward regions of the Dominican Republic. This region faces the usual social and economic problems of rural areas in developing countries and also tremendous degradation of its natural resource base. The economic structure of the region is dominated by marginal agricultural production of beans, pigeon peas, corn, coffee, cassava, plantain, rice and some extensive grazing. The area is characterized by widespread poverty of which visible symptoms are poor nutrition, low income, inadequate health care, high rates of illiteracy, poor communications, and high birth and death rates. Symptoms of the resource management problems include declining yields in agriculture, continued deforestation, soil erosion, low soil-water retention and downstream reservoir siltation.

Theoretically, most of the region should be maintained under natural forest and devoted to watershed protection since almost 80% of the watershed is characterized by high to very high erosion potential due to the dominance of steep slopes and high erosivity. Actually, most of the watershed has been deforested and devoted to marginal agriculture by peasants displaced from the surrounding lowland areas, as a result of land concentration and population growth that have taken place in the nation over the past fifty years. Though accelerated erosion affects most farmers, they only seem to concede importance to this problem when it has reached critical stages, such as the presence of gullies or very shallow soils. Similarly, private profitability of soil conservation seems to exist only on shallower soils, while on some deeper soils erosion appears as economically rational.

Conclusions

About 80% of the Las Cuevas watershed has a high to very high erosion potential. The major factors contributing to this high erosion potential are the abundance of long steep slopes, and the relatively high erosivity of rainfall. The influence of these factors is somewhat attenuated by the relatively low erodibility of the soil as a result of the medium to high organic content in the topsoil.

About 60% of the sampled farm area is under erosive cropping systems or under fallow; fallow land actually is part of the existing rainfed cropping systems. Rainfed multiple cropping of beans, pigeon peas and corn is the more extensive system practiced in the steeplands, but rotation of solely short-cycle and annual crops also is frequent. Soil-protective permanent crops, such as shaded coffee and plantain, cover only 12% of the sampled area and generally are planted in plots with low to medium slopes. Subtropical Dry Forest covers about 11% of the sampled area and is characterized by an abundance of gullies and rills, which may be explained by the scarcity of ground cover in combination with high slope gradients. Patches of open Pinus Occidentalis forest cover about 10% of the area and are located in the most remote parts of the watershed. Despite the national forest law, these stands frequently are threated by the inhabitants. Since it is forbidden to cut live trees people cut dead trees; they have replaced the old technique of slash-and-burn for the new one of burn-and-slash.

The greatest propensity to soil erosion during the year occurs in the period from the end of March to the middle of May, at the beginning of the rainy season. In this period, the percentage of ground cover is low, natural vegetation is very weak due to the preceeding dryness of almost three months, and crop land is being cleared and planted. The initial storms of the rainy season usually are intensive and find favorable conditions to bring about accelerated soil erosion.

Although farmers selectively allocate different land uses according to the variation of conditions found on the farm, the dominant criterion usually is not related to soil conservation needs but to household food consumption needs and soil water variations within the farm. The analysis of intrafarm organization showed how farmers tend to plant, for example, plantain and coffee on farm patches with lower slopes, where soil-water conditions are less variable during the year. A conservationist might condemn this practice as being contrary to the common recommendations of planting permanent crops on steep slopes and short cycle crops on low gradients, however the farmer in this case seems to be more worried about the output in terms of yield than in soil conservation. In rainfed agriculture, permanent crops are usually insurance against the more frequent failure of short cycle crops and, therefore, the farmer of rainfed land plants permanent crops on his best farmland.

The relevance of the three proposed erosion risk units, defined on the basis of the soil survey, was validated partially by the sample of farms. It was demonstrated that the moderate erosion risk area actually differs from the others in terms of erosion factors and economic performance. The high and very high erosion risk areas were not significantly different and, therefore, they should be combined into one unit. Thus two intermediate spatial areas are proposed for purposes of soil conservation planning: the moderate and the high-to-very-high erosion risk units. Different strategies and extension projects should be implemented in these areas.

Most of the farmers do not consider soil erosion as an important problem to be solved. Only 10% of the interviewed farmers referred explicitly to soil erosion as one of the three major problems on their farms. However, another 20% mentioned problems such as "tired fields", "lack of soil force" and "shallow soils", which could be related in some way to the problem of accelerated soil erosion. When farmers were asked explicitly about the importance they conceded to the erosion problem on their farms, 90% of them referred to it as having little or no importance at all.

The LWD achievements in soil conservation throughout the watershed are partial at best. After more than 8 years of work in the region, only 52 farmers had accepted the construction of some conservation structures or measures on their farms, but very few of them actually participated directly in that construction. In almost all cases, the maintenance of such structures has been a failure.

Discriminant analysis demonstrated that it is possible to ascertain farmers' perception of the importance of soil erosion with relatively few variables related to the environmental characteristics of the farms and the economic performance of the farmers. Perception of the importance of the soil erosion problem was stronger with low net revenues per unit of land, presence of active gullies, shallow soils and more steep slopes.

The analysis with the damage function indicated deferred conservation adoption where relatively deep solum is present but more immediate adoption under shallower eroded soils. Results show that yield damage and incentive to conserve may increase as topsoil is lost through erosion since the estimated yield functions exhibit diminishing marginal returns to soil depth. The long-run profitability of the conservation practice may compare favorably to traditional practices on steep slopes where erosion and yield damage are greater. These results are consistent with those of the discriminant analysis and represent a challange to soil conservation efforts in the region.

Recommendations

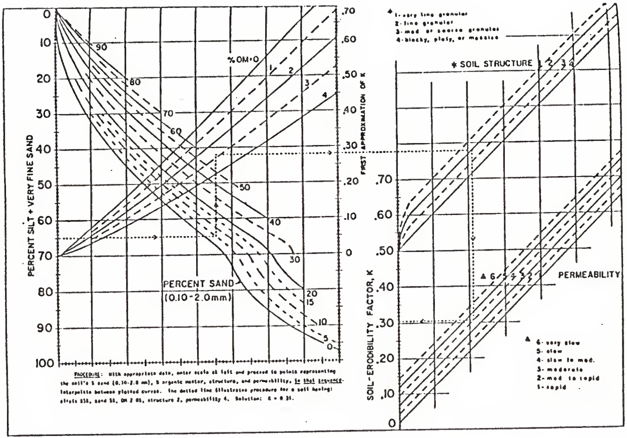
Institutions charged with planning and implementing soil conservation programs in the region should recognize that the possibilities for complete success are limited by the physical conditions of the area, the high degree of soil degradation, the scarcity of agricultural land, the people-food needs and the socioeconomic characteristics of the inhabitants. Under these circumstances, the initial objectives should not be formulated in terms of achieving fixed limits of soil erosion, but in terms of building community institutions through the generation of environmental awareness, the diffusion of inexpensive soil conserving techniques and the stimulation of economic off-farm activities.

Two spatial levels of planning for soil conservation emerge from this study: the soil erosion risk units and the individual farms. The erosion risk units, based on erosion potential evaluation, should serve as intermediate planning and extension areas to implement selected soil conserving strategies. The individual farms are the implementation units per se and each of them requires specific alternative plans of soil conservation according to intrafarm variations of erosion factors and farmers' personal characteristics. The plan should not be the automatic result of the application of the USLE, as it is done currently in the region, but the product of interpreting farmers' needs and perceptions, as well as their planning horizon.

Given the low degree of awareness of the erosion problem, the very limited success of the LWD efforts and the high cost of conservation structures, an intermediate approach seems more realistically achievable. Conservation systems for the smallholder should rely on the spatial organization of cropping activities within the farm, crop selection, mulching, cultivation practices, and the timing of these operations for their success, as opposed to the use of mechanically constructed erosion measures. In this regard, the testing of the feasibility of particular agroforestry systems in the region might offer possible alternatives.

The low level of environmental awareness suggests the need to carry out continued campaigns of nonformal environmental education and the formal incorporation of the environmental component into the elementary school programs. School teachers and children should participate actively in building community awareness and participation in soil conservation. Because many farmers are illiterate, conservation messages should be transmitted mainly through radio, meetings and graphic symbols.

APPENDIX I
ERODIBILITY DIAGRAM



PROCEDURE: With appropriate data, enter scale at left and proceed to points representing the soil's % sand (0.10-2.0 mm), % organic matter, structure, and permeability, in that sequence. Interpolate between plotted curves. The dotted line illustrates procedure for a soil having: si+vfs 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: K = 0.31.

APPENDIX II
SELECTION OF SAMPLE SIZE

Initial field observations, prior to designing the sample, suggested that variations in land use and land cover in the region were related in many ways to farm slopes. Thus, it was considered that slope variances could be used as a criterion for the sampling design since slope was related directly to erosion risk and, in some way, to land use.

Following Scheaffer et al. (1979), the approximate sample size, n, for this stratified random sampling is given by:

$$n = \frac{\sum_{i=1}^{3} \frac{Ni^2 Ti^2}{Wi}}{N^2 D + \sum_{i=1}^{3} NiTi^2}$$

where Ni is total number of farms in the erosion risk unit i; is slope variance in erosion risk unit i; is the fraction of the sample allocated to erosion risk unit i; and

$$D = \frac{B^2}{4}$$

where B is bound on the error of estimation, which was set to a 10% of the average slope for the study area. Average slope estimated from the soil survey was 27%, and therefore B was set to 2.7%.

According to cadastral information, there were 2154 farms in the watershed. Farms were distributed in the erosion risk units as follows:

Moderate erosion risk: 582 farms = N1.
High erosion risk: 1034 farms = N2.
Very high erosion risk: 538 farms = N3.

Slope variances in the erosion risk areas (estimated from the soil survey sampling) are:

1 = 390.06
2 = 268.20
3 = 506.94

The allocation of sampled farms to each erosion risk unit was set proportional to number of farms in each stratum, as follow:

W1 = 0.27
W2 = 0.48
W3 = 0.25

After substitution and solution for n, the approximate number of farms to be sampled was 194 and its allocation among the three strata was as follow:

n1 = 52
n2 = 93
n3 = 49

APPENDIX III
FIELD QUESTIONNAIRE

1. Entrevista numero ____
2. Localizacion de la finca (coordenadas) _________
3. Tipo de agricultor ____
   1 poseedor, 2 no poseedor.
4. Localizacion de la vivienda del agricultor ______
   1 Padre de las Casas, 2 Guayabal, 3 Monte Bonito, 4 Las Lagunas, 5 La Siembra, 6 Periquito, 7 Los Cambrones, 8 Miguel Martin, 9 Buena Vista, 10 Villa Ocoa, 11 San Jose de Ocoa, 12 Palma Cana, 13 Las Cuevas, 14 Los Naranjales, 15 Sabana de San Martin, 16 Arroyo La Vaca, 17 El Doce, 18 El Caiman, 19 Los Mangos, 20 El Naranjal, 21 La Raspadura, 22 La Coja, 23 Constanza, 24 El Recodo, 25 Quita Penas, 26 La Avispa, 27 La Guama, 28 A. Corrozo, 29 El Desecho, 30 Las Yayas, 31 Canada de Agua, 32 Polo Mocho, 33 El Palero, 34 La Meseta, 35 Los Indios, 36 Los Patios, 37 Lagunitas.
5. Distancia de la vivienda a la finca (kilometros) ________
6. Accceso a la vivienda ____
   1 camino, 2 carreteable, 3 carretera.
7. Acceso a la finca ____
   1 camino, 2 carreteable, 3 carretera.
8. Area de la finca (tareas) ___________
9. Porcentaje aproximado de tierra llana segun agricultor __________
10. Edad del agricultor, jefe de hogar ______
11. Nivel de educacion formal _____
12. Numero de personas habitando en la misma vivienda ______
13. Hombres de mas de 14 anos _______
14. Mujeres de mas de 14 anos _______
15. Hijos ausentes ______
16. Hijas ausentes ______
17. Principal fuente de ingreso ____
    1 agricultura, 2 ganaderia, 3 agricultura y ganaderia, 4 comercio, 5 agricultura y comercio, 6 agricultura y hecha-dia, 7 agricultura y empleo publico, 8 agricultura y dentisteria, 9 agricultura y construccion, 0 otros.
18. Numero de fincas operadas por el entrevistado ______
19. Numero de fincas pertenecientes al entrevistado _____
20. Principal uso de la finca muestreada _____
    0 suelo limpio o superficie rocosa; 1 solo cultivos de ciclo corto o cultivos anuales; 2 solo cultivos permanentes; 3 cultivos de ciclo corto o anuales y cultivos permanentes; 4 pastos y arboles aislados; 5 pastos y cultivos de ciclo corto o anuales; 6 pastos y cultivos permanentes; 7 cultivos de ciclo corto o anuales; cultivos permanentes y pastos; bosque seco; 9 bosque humedo.
21. Tiempo que el entrevistado a trabajado la finca (anos) _______
22. Tiempo transcurrido desde que se tala el bosque por primera vez _____.

23. Nombres de arboles en la finca antes de la primera tala

____

____

24. Zona de Vida en la que esta ubicada la finca ________
1 Bosque Seco Subtropical, 2 Bosque Humedo Subtropical, 3 Bosque Humedo Montano Bajo, 4 Bosque Muy Humedo Montano.

25. Unidad de erosion potencial en la cual esta ubicada la finca _____
1 moderada, 2 alta, 3 muy alta.

26. Clase de uso de la tierra en la finca, diez anos atras

____

27. Numero actual de predios dentro de la finca __________
(un predio es un pedazo de tierra con un uso especifico)

Predio 1

25. Rotacion tipica de cultivos ____________________________________

____

____

26. Area del predio (tareas) __________
27. Altitud media (metros) ___________
28. Pendiente media (%) ______________
29. Longitud media de la pendiente (metros) ______________
30. Profundidad del horizonte superficial (centimetros) ___________
31. Profundidad total del solum (centimetros) ____________
32. Estructura del horizonte superficial __________________________

____

33. Textura del horizonte superficial ________________
34. Irrigacion ______ 1 si, 2 no
35. Clase de capacidad de uso de la tierra _______________
36. Presencia de carcavas ______________________________
0 no hay, 1 carcavas estabilizadas, 2 carcavas activas
37. Presencia de surcos ________________________________
0 no hay, 1 surcos estabilizados, 2 surcos activos
38. Presencia de deslizamientos __________________________
0 no hay, 1 d. estabilizados, 2 d. activos
39. Tipo de fuente de agua en el predio ___________________
0 no hay, 1 manantial permanente, 2 manantial estacional, 3 arroyo permanente, 4 arroyo estacional, 5 canal, 6 manguera, 7 tuberia
40. Practicas de conservacion de suelo en el predio ______________

____

____

____

41. Practicas que evidentemente contribuyen a acelerar la erosion en el predio ____

____

____

42. Uso de fertilizantes ______ 0 no, 1 si
43. Uso de insecticidas ______ 0 no, 1 si
44. Uso de herbicidas ______ 0 no, 1 si
45. Tecnica de preparar el terreno ______ 0 solo chapeo, 1 solo chapeo y quema, 2 chapeo, quema y remocion manual, 3 chapeo, quema y arado con traccion animal, 4 chapeo, quema y arado mecanizado, 5 limpieza sin quema, arado con traccion animal, 6 limpieza sin quema, arado mecanizado.

46. Costo total anual de produccion del predio __________
47. Retorno total anual de la produccion del predio _____
48. Rendimiento de las habichuelas por tarea ___________
49. Rendimiento del cafe por tarea ______________________

Predio 2

50. Rotacion tipica de cultivos ___________________________________
____
____
51. Area del predio (tareas) __________
52. Altitud media (metros) ____________
53. Pendiente media (%) ______________
54. Longitud media de la pendiente (metros) _____________
55. Profundidad del horizonte superficial (centimetros) ___________
56. Profundidad total del solum (centimetros) ____________
57. Estructura del horizonte superficial ___________________________
____
58. Textura del horizonte superficial ___________________
59. Irrigacion ______ 1 si, 2 no
60. Clase de capacidad de uso de la tierra ______________
61. Presencia de carcavas _____________________________
0 no hay, 1 carcavas estabilizadas, 2 carcavas activas
62. Presencia de surcos _______________________________
0 no hay, 1 surcos estabilizados, 2 surcos activos
63. Presencia de deslizamientos _________________________
0 no hay, 1 d. estabilizados, 2 d. activos
64. Tipo de fuente de agua en el predio __________________
0 no hay, 1 manantial permanente, 2 manantial estacional, 3 arroyo permanente, 4 arroyo estacional, 5 canal, 6 manguera, 7 tuberia
65. Practicas de conservacion de suelo en el predio _________________
____
____
____
66. Practicas que evidentemente contribuyen a acelerar la erosion en el predio ____
____
____
67. Uso de fertilizantes ______ 0 no, 1 si
68. Uso de insecticidas ______ 0 no, 1 si
69. Uso de herbicidas ______ 0 no, 1 si
70. Tecnica de preparar el terreno ______ 0 solo chapeo, 1 solo chapeo y quema, 2 chapeo, quema y remocion manual, 3 chapeo, quema y arado con traccion animal, 4 chapeo, quema y arado mecanizado, 5 limpieza sin quema, arado con traccion animal, 6 limpieza sin quema, arado mecanizado.
71. Costo total anual de produccion del predio __________
72. Retorno total anual de la produccion del predio _____
73. Rendimiento de las habichuelas por tarea ___________
74. Rendimiento del cafe por tarea ______________________

Predio 3

75. Rotacion tipica de cultivos ____

____

____

76. Area del predio (tareas) __________
77. Altitud media (metros) ____________
78. Pendiente media (%) _______________
79. Longitud media de la pendiente (metros) ______________
80. Profundidad del horizonte superficial (centimetros) ___________
81. Profundidad total del solum (centimetros) ____________
82. Estructura del horizonte superficial ____________________________

____

83. Textura del horizonte superficial ___________________
84. Irrigacion ______ 1 si, 2 no
85. Clase de capacidad de uso de la tierra _____________
86. Presencia de carcavas ________________________________ 0 no hay, 1 carcavas estabilizadas, 2 carcavas activas
87. Presencia de surcos __________________________________ 0 no hay, 1 surcos estabilizados, 2 surcos activos
88. Presencia de deslizamientos __________________________ 0 no hay, 1 d. estabilizados, 2 d. activos
89. Tipo de fuente de agua en el predio __________________ 0 no hay, 1 manantial permanente, 2 manantial estacional 3 arroyo permanente, 4 arroyo estacional, 5 canal, 6 manguera, 7 tuberia
90. Practicas de conservacion de suelo en el predio ______________

____

____

91. Practicas que evidentemente contribuyen a acelerar la erosion en el predio ____

____

____

92. Uso de fertilizantes ______ 0 no, 1 si
93. Uso de insecticidas ______ 0 no, 1 si
94. Uso de herbicidas ______ 0 no, 1 si
95. Tecnica de preparar el terreno ______ 0 solo chapeo, 1 solo chapeo y quema, 2 chapeo, quema y remocion manual, 3 chapeo, quema y arado con traccion animal, 4 chapeo, quema y arado mecanizado, 5 limpieza sin quema, arado con traccion animal, 6 limpieza sin quema, arado mecanizado.
96. Costo total anual de produccion del predio __________
97. Retorno total anual de la produccion del predio _____
98. Rendimiento de las habichuelas por tarea ____________
99. Rendimiento del cafe por tarea ______________________

Predio 4

100. Rotacion tipica de cultivos ____

____

____

101. Area del predio (tareas) __________
102. Altitud media (metros) ____________
103. Pendiente media (%) _______________

104. Longitud media de la pendiente (metros) ____________
105. Profundidad del horizonte superficial (centimetros) ____________
106. Profundidad total del solum (centimetros) ____________
107. Estructura del horizonte superficial ____________________________
____
108. Textura del horizonte superficial ____________________
109. Irrigacion ______ 1 si, 2 no
110. Clase de capacidad de uso de la tierra ____________
111. Presencia de carcavas ____
0 no hay, 1 carcavas estabilizadas, 2 carcavas activas
112. Presencia de surcos ____
0 no hay, 1 surcos estabilizados, 2 surcos activos
113. Presencia de deslizamientos __________________________________
0 no hay, 1 d. estabilizados, 2 d. activos
114. Tipo de fuente de agua en el predio ___________________________
0 no hay, 1 manantial permanente, 2 manantial estacional, 3 arroyo permanente, 4 arroyo estacional, 5 canal, 6 manguera, 7 tuberia
115. Practicas de conservacion de suelo en el predio ________________
____
____
____
116. Practicas que evidentemente contribuyen a acelerar la erosion en el predio ____
____
____
117. Uso de fertilizantes ______ 0 no, 1 si
118. Uso de insecticidas ______ 0 no, 1 si
119. Uso de herbicidas ______ 0 no, 1 si
120. Tecnica de preparar el terreno ______ 0 solo chapeo, 1 solo chapeo y quema, 2 chapeo, quema y remocion manual, 3 chapeo, quema y arado con traccion animal, 4 chapeo, quema y arado mecanizado, 5 limpieza sin quema, arado con traccion animal, 6 limpieza sin quema, arado mecanizado.
121. Costo total anual de produccion del predio __________
122. Retorno total anual de la produccion del predio _____
123. Rendimiento de las habichuelas por tarea ___________
124. Rendimiento del cafe por tarea ________________

125. Principales problemas de su finca segun el entrevistado, en orden de importancia ____
____
____
____
126. Que tan importante es para el agricultor el problema del arrastre del suelo por el agua en su finca ______ 0 no tiene ninguna importancia, 1 tiene poca importancia, 2 es importante, 3 muy importante, 4 es extremadamente importante.
127. Por que es o no importante el problema del arrastre del suelo por el agua en su finca ____
____
____
128. El rendimiento actual de la finca es mejor que la de cinco anos ______ 1 si, 2 no, 3 igual, 4 no sabe que decir

129. Segun el agricultor, cuales son las causas del mayor o menor rendimiento actual ______________________________
____
____
____

130. Segun el agricultor, llueve ahora mas que hace cinco anos? ______
0 no, 1 si, 2 igual

131. Segun el agricultor, cuales son las causas de que ahora llueva mas o menos? ______________________________
____
____

132. Segun el entrevistado, por que casi siempre el terreno llano es mejor que la "jalda"? ______________________________
____
____
____

133. El agricultor ha asistido alguna vez a charlas sobre conservacion del suelo? ______ 1 no, 2 si

134. Se han hecho trabajos de conservacion de suelo en la finca? _____
0 no, 1 si

135. Area de la finca con trabajos de conservacion (Tareas) __________

136. Clase de trabajos de conservacion ____________________
____
____

137. Antiguedad de esos trabajos de conservacion _________

138. Participo el agricultor en la construccion de las obras de conservacion? ______________________________ 1 no, 2 si

139. Considera el entrevistado que la produccion agricola, despues de haber estado practicando trabajos de conservacion, es ______
1 igual que antes, 2 mayor que antes, 3 menor que antes

140. Estaria el entrevistado dispuesto a costear trabajos conservacion de suelos, con la orientacion de la Oficina de Tierras y Aguas?
______ 0 no, 1 si
Razones ____
____
____

141. Le gustaria al entrevistado sembrar arboles en su finca?
________ 0 no, 1 si

142. Con que fin sembraria arboles? ______________________________
____
____

143. Hasta cuando espera el entrevistado trabajar la finca?
____

APPENDIX IV
DISCRIMINANT ANALYSIS CLASSIFICATION FOR EACH FARMER

```
   LAS CUEVAS                                  DICRIMINANT ANALYSIS                        16:03 MONDAY, NOVEMBER 12, 1984
                                                                                      TUTLE2 LAS CUEVAS FARMERS

           DISCRIMINANT ANALYSIS     CLASSIFICATION RESULTS FOR CALIBRATION DATA: WORK.DATA1

GENERALIZED SQUARED DISTANCE FUNCTION:                             POSTERIOR PROBABILITY OF MEMBERSHIP IN EACH PROD:

 2                     -1                                                        2                      2
D (X) = (X-X̄ )' COV  (X-X̄ ) + LN |COV | - 2 LN PRIOR          PR(J|X) = EXP(-.5 D (X)) / SUM EXP(-.5 D (X))
 J          J       J     J           J               J                           J            K          K

                                                                                 POSTERIOR PROBABILITY OF MEMBERSHIP IN PROD:
                           OBS          FROM      CLASSIFIED         0         1
                                        PROD       INTO PROD

                             1            0               0      0.9782    0.0218
                             2            0               0      0.9724    0.0276
                             3            0               0      0.7188    0.2812
                             4            0               0      0.9889    0.0111
                             5            0               0      0.9727    0.0273
                             6            0               0      0.6665    0.3335
                             7            1               1      0.0000    1.0000
                             8            0               0      0.9994    0.0006
                             9            0               0      0.9999    0.0001
                            10            1               0 *    0.9998    0.0002
                            11            0               0      0.8976    0.1024
                            12            0               0      1.0000    0.0000
                            13            0               0      1.0000    0.0000
                            14            0               0      0.9998    0.0002
                            15            0               0      0.9606    0.0394
                            16            0               0      0.9152    0.0848
                            17            0               0      0.9869    0.0131
                            18            0               0      0.9996    0.0004
                            19            0               0      0.9870    0.0130
                            20            0               0      0.9999    0.0001
                            21            0               0      0.9972    0.0028
                            22            0               0      0.7883    0.2117
                            23            0               0      0.8578    0.1422
                            24            0               0      0.6514    0.3486
                            25            0               0      0.9819    0.0181
                            26            0               0      0.9908    0.0092
                            27            0               0      0.9062    0.0938
                            28            0               0      0.8386    0.1614
                            29            0               0      0.8066    0.1934
                            30            0               0      0.6223    0.3777
                            31            1               1      0.2400    0.7600
                            32            0               0      1.0000    0.0000
                            33            0               0      0.5403    0.4597
                            34            0               0      0.8775    0.1225
                            35            0               1 *    0.4783    0.5217
                            36            0               0      0.6084    0.3916
                            37            0               0      0.7851    0.2149
                            38            1               0 *    0.8876    0.1124
```

```
39          0          0     0.9969  0.0031
40          0          0     0.8283  0.1717
41          0          0     0.9016  0.0984
42          0          0     0.9145  0.0855
43          0          0     0.9429  0.0571
44          0          0     0.8822  0.1178
45          0          0     0.9691  0.0309
46          0          0     0.7271  0.2729
47          0          0     0.9996  0.0004
48          0          0     0.9992  0.0008
49          0          0     0.8854  0.1146
50          1          0 *   0.8195  0.1805
51          1          0 *   0.8881  0.1119
52          0          0     0.6730  0.3270
53          1          0 *   0.8632  0.1368
54          1          1     0.4106  0.5894
55          0          0     0.9726  0.0274
56          0          0     0.8759  0.1241
57          0          1 *   0.0688  0.9312
58          0          0     0.9516  0.0484
59          1          1     0.4382  0.5618
60          0          0     0.6672  0.3328
61          0          1 *   0.4742  0.5258
62          0          0     0.7490  0.2510
63          1          0 *   0.8788  0.1212
64          0          1 *   0.2516  0.7484

65          1          0 *   0.6556  0.3444
66          0          1 *   0.4728  0.5272
67          0          1 *   0.3213  0.6787
68          0          0     0.8740  0.1260
69          0          0     0.8348  0.1652
70          1          0 *   0.5589  0.4411
71          0          0     0.7424  0.2576
72          1          1     0.3424  0.6576
73          0          0     0.8019  0.1981
74          1          0 *   0.5011  0.4989
75          1          1     0.2910  0.7090
76          0          0     0.8683  0.1317
77          0          0     0.6904  0.3096
78          1          1     0.3915  0.6085
79          0          0     0.6153  0.3847
80          0          0     0.9140  0.0860
81          0          0     0.6305  0.3695
82          1          0 *   0.5466  0.4534
83          1          0 *   0.5300  0.4700
84          1          1     0.4696  0.5304
85          0          0     0.7120  0.2880
86          1          0 *   0.7416  0.2584
87          0          1 *   0.4735  0.5265
88          0          0     0.9845  0.0155
89          0          0     1.0000  0.0000
90          0          0     0.6956  0.3044
91          0          0     0.6980  0.3020
92          0          0     0.9942  0.0058
93          0          0     0.9978  0.0022
94          0          0     0.7495  0.2505
95          1          1     0.2148  0.7852
96          1          1     0.0023  0.9977
97          1          0 *   0.6603  0.3397
98          0          0     0.8884  0.1116
```

```
  99          1           0 *   0.6388  0.3612
 100          0           0     0.6049  0.3951
 101          0           0     0.5880  0.4120
 102          1           0 *   0.7608  0.2392
 103          0           0     0.8781  0.1219
 104          0           0     0.8286  0.1714
 105          0           0     0.8548  0.1452
 106          1           1     0.1228  0.8772
 107          1           0 *   0.7549  0.2451
 108          0           1 *   0.4332  0.5668
 109          0           1 *   0.4406  0.5594
 110          0           1 *   0.2824  0.7176
 111          1           1     0.2669  0.7331
 112          1           1     0.3225  0.6775
 113          1           1     0.3296  0.6704
 114          1           1     0.2081  0.7919
 115          1           0 *   0.7999  0.2001
 116          1           0 *   0.7973  0.2027
 117          0           0     0.5640  0.4360
 118          0           0     0.9365  0.0635
 119          0           0     0.7596  0.2404
 120          0           0     0.9570  0.0430
 121          0           0     0.9584  0.0416
 122          0           0     0.9999  0.0001
 123          0           0     0.8211  0.1789
 124          0           0     0.7651  0.2349
 125          0           1 *   0.4089  0.5911
 126          1           1     0.2298  0.7702
 127          0           0     0.8630  0.1370
 128          1           1     0.1706  0.8294
 129          1           1     0.3636  0.6364
 130          0           0     0.9250  0.0750
 131          0           0     0.5555  0.4445
 132          0           1 *   0.4499  0.5501
 133          0           1 *   0.4769  0.5231
 134          0           0     0.5886  0.4114
 135          1           1     0.4053  0.5947
 136          1           1     0.3751  0.6249
 137          0           0     1.0000  0.0000
 138          0           0     0.7872  0.2128
 139          0           0     0.8025  0.1975
 140          1           1     0.3372  0.6628
 141          0           1 *   0.3344  0.6656
 142          0           1 *   0.3869  0.6131
 143          0           0     0.9069  0.0931
 144          0           0     0.7772  0.2228
 145          0           0     0.5542  0.4458
 146          1           0 *   0.8407  0.1593
 147          1           1     0.3531  0.6469
 148          1           0 *   0.6607  0.3393
 149          0           1 *   0.3801  0.6199
 150          0           1 *   0.4861  0.5139
 151          0           0     0.5882  0.4118
 152          0           0     0.5827  0.4173
 153          0           0     1.0000  0.0000
 154          0           0     0.8074  0.1926
 155          0           0     0.5734  0.4266
 156          0           0     0.9989  0.0011
 157          0           0     0.6107  0.3893
 158          1           1     0.4087  0.5913
 159          0           0     0.7754  0.2246
```

```
160          0          1 *   0.4181   0.5819
161          0          1 *   0.4476   0.5524
162          0          0     0.6266   0.3734
163          0          0     0.7170   0.2830
164          1          1     0.2073   0.7927
165          1          0 *   0.9955   0.0045
166          1          0 *   0.6228   0.3772
167          0          0     0.8325   0.1675
168          1          1     0.4723   0.5277
169          1          1     0.4555   0.5445
170          1          0 *   0.5360   0.4640
171          0          1 *   0.1480   0.8520
172          1          1     0.4360   0.5640
173          0          0     0.6354   0.3646
174          0          0     0.7399   0.2601
175          0          0     0.8830   0.1170
176          1          0 *   0.6061   0.3939
177          0          1 *   0.4541   0.5459
178          0          0     0.6795   0.3205
179          0          0     0.7893   0.2107
180          0          0     0.9984   0.0016
181          0          0     0.6574   0.3426
182          0          1 *   0.1637   0.8363
183          1          0 *   0.7900   0.2100
184          1          0 *   0.6093   0.3907
185          1          0 *   0.8563   0.1437
186          1          1     0.2355   0.7645
187          1          1     0.3720   0.6280
188          0          0     0.5171   0.4829
189          1          1     0.1764   0.8236
190          1          0 *   0.6215   0.3785
191          0          1 *   0.1702   0.8298
192          0          0     0.9973   0.0027
193          0          0     0.6181   0.3819
194          0          1 *   0.2752   0.7248
195          0          0     0.7302   0.2698
196          1          1     0.4323   0.5677
197          0          1 *   0.2284   0.7716
198          0          1 *   0.0000   1.0000
199          0          0     1.0000   0.0000
200          0          0     1.0000   0.0000
201          0          1 *   0.4020   0.5980
202          1          0 *   0.8055   0.1945
203          0          1 *   0.3611   0.6389
204          0          0     0.5611   0.4389
205          0          0     0.6732   0.3268
206          0          0     0.5830   0.4170
207          0          0     0.5644   0.4356
208          0          1 *   0.3830   0.6170
209          1          1     0.4664   0.5336
210          0          0     0.8801   0.1199

       * MISCLASSIFIED OBSERVATION
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LAS CUEVAS W                             DICRIMINANT ANALYSIS                       16:03 MONDAY, NOVEMBER 12, 1984
                                                                                 TUTLE2 LAS CUEVAS FARMERS
           DISCRIMINANT ANALYSIS     CLASSIFICATION SUMMARY FOR CALIBRATION DATA: WORK.DATA1

GENERALIZED SQUARED DISTANCE FUNCTION:                          POSTERIOR PROBABILITY OF MEMBERSHIP IN EACH PROB:
 2                   -1                                                         2                      2
D (X) = (X-X̄ )' COV  (X-X̄ ) + LN |COV | - 2 LN PRIOR           PR(J|X) = EXP(-.5 D (X)) / SUM EXP(-.5 D (X))
 J          J       J      J          J               J                          J        K            K

                                                             NUMBER OF OBSERVATIONS AND PERCENTS CLASSIFIED INTO PROB:
                                         FROM
                                         PROB          0         1    TOTAL

                                           0         120        29      149
                                                   60.54     19.46   100.00

                                           1          29        32       61
                                                   47.54     52.46   100.00

                                   TOTAL             149        61      210
                                   PERCENT         70.95     29.05   100.00

                                   PRIORS         0.7095    0.2905
```

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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